

# UltraLight Steel Auto Closures

## PROJECT OVERVIEW

### 1. Introduction

The UltraLight Steel Auto Closure (ULSAC) concept study has generated steel closure concepts that are lightweight, structurally sound, manufacturable and affordable. ULSAC demonstrates closure concepts that are up to 32 percent lighter than benchmarked averages and meet stringent structural performance targets. They can be fabricated using manufacturing processes and materials that are current and affordable. The concept phase is the first step in the project and provides the opportunity to build demonstration closures.

These impressive results were obtained largely through design concepts that feature technologies such as tailored blanking and hydroforming and materials such as steel sandwich and high and ultra high strength steels.

Like the UltraLight Steel Auto Body (ULSAB) study, the ULSAC study was commissioned by an international consortium of sheet steel producers to assist their automotive customers with viable lightweighting solutions. While the ULSAB study focused on lightweighting the automotive body structure, ULSAC investigates doors, hoods, decklids and hatchbacks. The ULSAC consortium contracted Porsche Engineering Services, Inc. (PES) in Troy, Mich., to provide engineering management for the project and also worked with them to define the project goals.

### 2. Goals

ULSAC project goals were to define state-of-the-art closures and develop lightweight steel closure concepts that are structurally sound at an affordable cost.

### 3. Approach

The project approach encompassed benchmarking, target setting and conceptual design, which includes FEA calculation and cost analysis. Benchmarking was performed to define current state-of-the-art design concepts; target setting provided specific objectives to aim for; and conceptual design was undertaken to demonstrate ideas that would meet the established targets and to produce data to support the concepts.

### 4. Benchmarking

PES benchmarked the following 1997 models:

|                        |                    |
|------------------------|--------------------|
| Audi A6                | Mercedes E320      |
| BMW 528i               | Mitsubishi Eclipse |
| Cadillac Sedan Deville | Nissan Sentra      |
| Chevrolet Malibu       | Porsche Boxster    |
| Dodge Stratus          | Renault Laguna     |
| Ford Contour           | Saturn LS          |
| Ford Probe             | Toyota Camry       |
| Ford Taurus            | VW Golf            |
| Honda Accord           | VW Passat          |



door



hood



decklid



hatch

The benchmark vehicles were chosen to provide specific design concepts to evaluate. For the door these included roof integrated, frame integrated and frameless. Hood design concepts included conventional and grille integrated. The decklid design was the conventional with a tail and the hatch designs were the lift gate type.

The benchmark study established mass (without glass), dimension and structural performance standards for doors, hoods, decklids and hatchbacks. PES normalized this data to make accurate comparisons among the closures and then evaluated designs and components of the benchmarked closures. In addition, PES assessed costs associated with manufacturing each of the closures.

#### 4.1 Doors

Door mass data was collected for the assembly complete, sheet metal and subsystems such as glass, the window regulator, electrical components, latch, lock and hinges, trim and sealing.

Doors were measured for length, height and beltline/bottom, and all measurements include the surface curvature. Length is the longest longitudinal distance along the door from the forward to the rearward most points. Height is the distance from the bottom edge of the door outer panel to the top edge of the frame. The beltline/bottom is the distance from the bottom of the door to the bottom edge of the window opening. PES used these measurements to help calculate true surface area. Material thicknesses were captured with an ultrasonic thickness gage and averaged 0.7 mm for the inner panels and 0.7 mm for the outer panels.

Structural performance test methods and specifications were collected through a survey of respective automakers for each of the benchmarked doors. These specifications represent OEM internal targets and include frame rigidity, door sag, torsional rigidity and check load.

## 4.2 Hoods

Hood mass data was collected for the assembly complete, sheet metal and subsystems such as the strikers, insulation, sealing and hinges.

Hoods were measured for length and width, the length being the longitudinal distance down the centerline and the width being the plan view width of the hood at its midpoint. All measurements include the surface curvature. PES used these measurements to help calculate true surface area. Material thicknesses were captured with an ultrasonic thickness gage and averaged 0.6 mm for the inner panels and 0.7 mm for the outer panels.

Structural performance test methods and specifications were collected through a survey of respective automakers for each of the benchmarked hoods. These specifications represent OEM internal targets and include torsional rigidity, bending stiffness and side beam stiffnesses.

## 4.3 Decklids

Decklid mass data was collected for the assembly complete, sheet metal and subsystems such as the lock, trim and sealing.

Decklids were measured for length and width, the length being the longitudinal axis along the centerline, including the tail and the width being the plan view width at the widest point. All measurements include the surface curvature. PES used these measurements to help calculate true surface area. Material thicknesses were captured with an ultrasonic thickness gage and averaged 0.7 mm for the inner panels and 0.7 mm for the outer panels.

Structural performance test methods and specifications were collected through a survey of respective automakers for each of the benchmarked decklids.

These specifications represent OEM internal targets and include torsional rigidity, bending stiffness, side beam stiffnesses and tail stiffness.

## 4.4 Hatch

Mass data for the hatch was collected for the assembly complete, sheet metal and subsystems such as glass, lock and latch, trim and hinges.

Hatches were measured for length and width. Length measurements followed the surface contour and were calculated along the longitudinal axis down the centerline. Width measurements were taken across the hatch at midpoint. All measurements include the surface curvature. PES used these measurements to help calculate true surface area. Material thicknesses were captured with an ultrasonic thickness gage and averaged 0.7 mm for the inner panels and 0.8 mm for the outer panels.

Structural performance test methods and specifications were collected through a survey of respective automakers for the benchmarked hatch. These specifications represent OEM internal targets and include torsional rigidity and bending stiffness.

## 4.5 Components

As part of benchmarking, PES also reviewed components for each of the closures. This exercise enabled them to discover the lightest solutions for the component and to find individual components that aid in weight reduction of the whole system. Components reviewed comprised hinge types, check systems, latch types, window regulator systems and modular systems.

## 4.6 Data

To process all this data for comparison, PES normalized mass, determined the length to hinge spread

ratio and calculated the mass breakdown of each closure. Mass was normalized by dividing the outer surface area into the mass.

Normalized mass

| Closure | Normalized mass range (kg/m <sup>2</sup> ) | Average normalized mass (kg/m <sup>2</sup> ) |
|---------|--------------------------------------------|----------------------------------------------|
| Door    | 17.0-23.4                                  | 19.7                                         |
| Hood    | 8.8-14.2                                   | 11.5                                         |
| Decklid | 8.9-16.1                                   | 11.2                                         |
| Hatch   | 12.5-15.4                                  | 13.9                                         |

The calculation of normalized mass allowed for the mass of paint and gum drops, as specified below.

Mass allowance

| Closure | Paint (kg) | Gum drops (kg) |
|---------|------------|----------------|
| Door    | 0.15       | N/A            |
| Hood    | 0.2        | 0.15           |
| Decklid | 0.2        | 0.15           |
| Hatch   | 0.15       | N/A            |

The hinge spread ratio is an indication of stiffness that can be expected in the closure. As a general rule, the smaller the ratio, the stiffer the closure system. Hinge spread ratio is calculated by dividing the hinge spread into the length. This calculation resulted in a range for the door of 2.7:1 to 4.2:1; for the hood of 0.6:1 to 1.0:1; for the decklid of 0.6:1 to 0.9:1; and for the hatchback of 1.4:1.

PES also calculated mass breakdown to discover opportunities for greatest mass reduction. Calculations for mass breakdown revealed that structure represented approximately 50 percent of the mass of the doors. For hoods and decklids, that number increased to approximately 90 percent. The structure in hatches accounts for about 45 percent of the mass.

After gathering this benchmarking data and processing it appropriately, PES developed mass and performance targets for the closure designs.

## 5. Target setting

PES developed targets for dimensions, structural performances and mass for doors, hoods, decklids and hatches. Dimensional targets for doors, hoods and decklids were based on ULSAB styling surface dimensions because those dimensions were very close to ULSAC benchmarked averages and they provided PES the outer surface data it needed to conduct this closure study. For hatch dimensional targets, PES used the measurements from a lift gate type hatch, which was the lightest and smallest one benchmarked. Structural performance targets were set at the midpoint in the range from the OEM survey. Mass targets, however, were set for 10 percent better than best-in-class of the benchmarked closures.

Door targets

|                                      |                           | Benchmark    | Targets        |
|--------------------------------------|---------------------------|--------------|----------------|
| Dimension (mm)                       |                           |              |                |
|                                      | Length                    | 1085         | 1079           |
|                                      | Height                    | 1160         | 1248           |
|                                      | Beltline/bottom           | 643          | 740            |
| Normalized mass (kg/m <sup>2</sup> ) |                           | 19.7         | 15.5           |
| Structural performance               |                           |              |                |
|                                      | Frame rigidity front/rear | 43 (N/mm)    | ≥ 43 N/mm      |
|                                      | Door sag                  | 287 (N/mm)   | ≥ 287 N/mm     |
|                                      | Torsional Rigidity        | 94 (N/mm)    | ≥ 94 N/mm      |
|                                      | Check load                | 1.2 mm (set) | < 1.2 mm (set) |

Hood targets

|                                      |                       | Benchmark | Targets |
|--------------------------------------|-----------------------|-----------|---------|
| Dimension (mm)                       |                       |           |         |
|                                      | Length                | 1122      | 1283    |
|                                      | Width                 | 1455      | 1402    |
| Normalized mass (kg/m <sup>2</sup> ) |                       | 11.6      | 8.0     |
| Structural performance (N/mm)        |                       |           |         |
|                                      | Torsional rigidity    | 5.7       | ≥ 5.7   |
|                                      | Bending stiffness     | 4.5       | ≥ 4.5   |
|                                      | Side beam stiffnesses | 110       | ≥ 110   |

#### Decklid targets

|                                      |                       | Benchmark | Targets |
|--------------------------------------|-----------------------|-----------|---------|
| Dimension (mm)                       |                       |           |         |
|                                      | Length                | 1085      | 1079    |
|                                      | Width                 | 1220      | 1241    |
| Normalized mass (kg/m <sup>2</sup> ) |                       | 11.2      | 8.0     |
| Structural performance (N/mm)        |                       |           |         |
|                                      | Torsional rigidity    | 5.7       | ≥ 5.7   |
|                                      | Bending stiffness     | 4.5       | ≥ 4.5   |
|                                      | Side beam stiffnesses | 110       | ≥ 110   |
|                                      | Tail stiffness        | 21        | ≥ 21    |

#### Hatch targets

|                                      |                    | Benchmark | Targets |
|--------------------------------------|--------------------|-----------|---------|
| Dimension (mm)                       |                    |           |         |
|                                      | Length             | 1353      | 930     |
|                                      | Width              | 1253      | 1335    |
| Normalized mass (kg/m <sup>2</sup> ) |                    | 13.9      | 11.3    |
| Structural performance (N/mm)        |                    |           |         |
|                                      | Torsional rigidity | 3.5       | ≥ 3.5   |
|                                      | Bending stiffness  | 4.5       | ≥ 4.5   |

## 6. Conceptual design

With targets defined, PES developed conceptual designs for each of the closures. ULSAC's design team started with a "clean sheet of paper" and used an iterative holistic approach to design, whereby the structure is treated as an integrated system rather than as an assembly of individual components. The holistic approach emphasizes total structure analysis. Sophisticated computer models aid the process and confirm the effectiveness of the latest optimizations. This approach promotes weight savings and improved structural integrity by enabling engineers to

reduce weight in certain areas while strengthening strategic locations. The net effect is the creation of a more efficient structure.

PES evaluated the closure design concepts selected in the early part of the study and developed optimized solutions. Then they specified materials, processes and joining technologies that would enable them to meet their targets. To guide their efforts at this stage, PES reviewed manufacturing processes they might recommend for the closures and assigned a value to them based on criteria such as feasibility, mass savings and tool cost, to name a few. Based on this subjective analysis, PES directed its attention to design concepts that employed the manufacturing processes that cumulated the most promising scores.

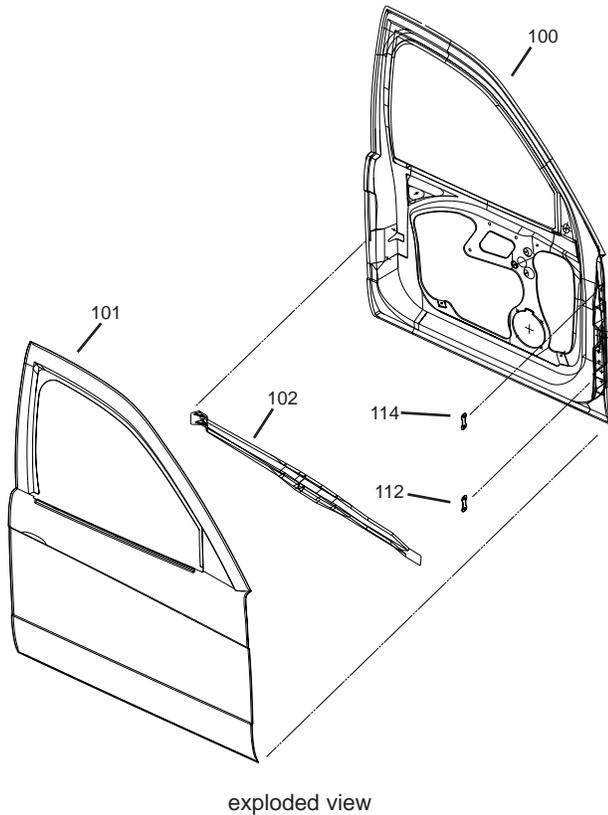
Another initial consideration concerned dent resistance and oil canning. PES guarded against these two problems by following several conventional techniques:

- Feature lines were added to outer panels to stiffen unsupported areas
- Inner panel structures were designed to provide good support to outer panels
- Sheet metal hydroforming was used to increase effective outer panel dent resistance through work hardening
- High strength steel was used for outer panels

All closures are designed to the dimensions identified in the target setting phase of this study. Design concepts for the door included roof integrated, frame integrated and frameless; for the hood it included conventional and grille integrated; for the decklid it included the conventional with a tail; and for the hatch it included the lift gate type.

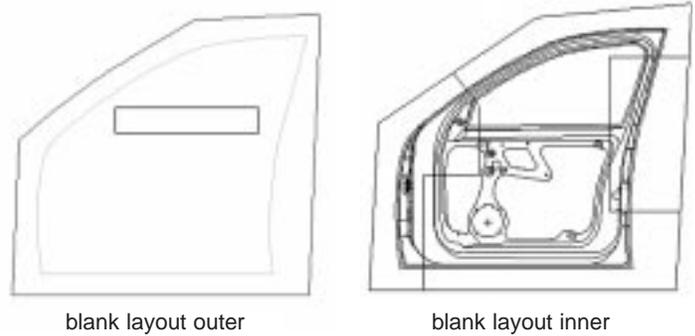
## 6.1 Door

### 6.1.1 Roof integrated



### Design highlights

The roof integrated design concept employs a 0.7 mm sheet hydroformed outer panel with feature lines to improve dent resistance and oil canning. PES saves mass and improves formability in the inner panel by specifying non-linear weld lines in the tailored blank. Additional mass savings in this part are gained by using a double cable window regulator thereby eliminating the lower glass drop channels. The tailored blank outer panel reinforces the belt area, increasing stiffness there. High strength steel is specified in the hinge area to withstand sag and check load stresses.

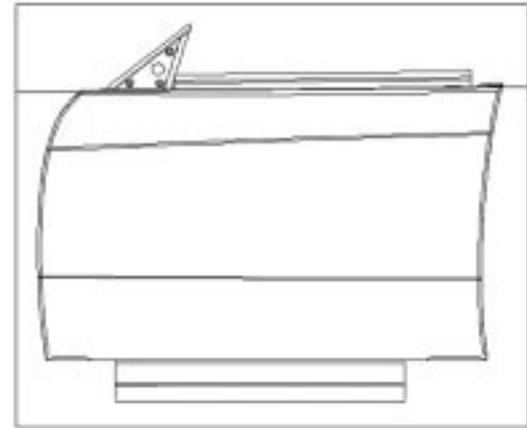
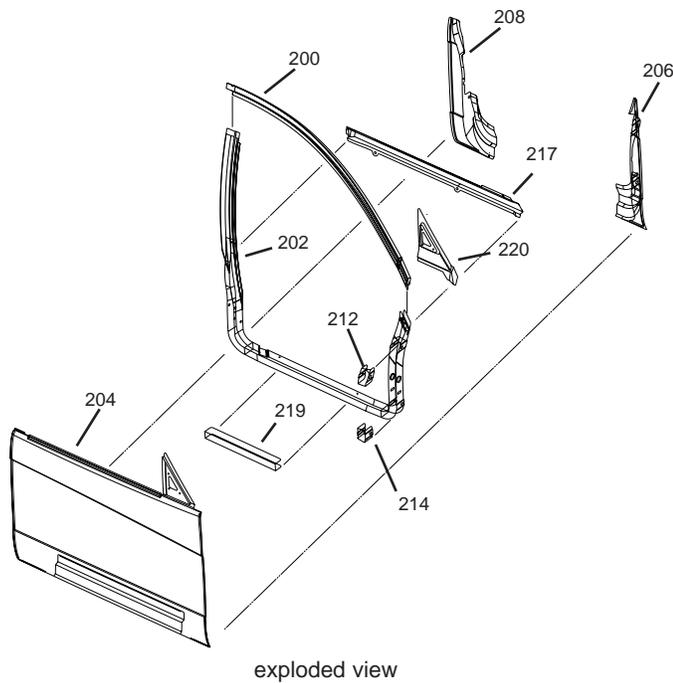


This design results in the creation of a structure with a normalized mass of 15.1 kg/m<sup>2</sup> compared with the target of 15.5 kg/m<sup>2</sup>. It is 23 percent lighter than the benchmarked average.

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material      | Joining Technology                |
|--------------------------------------|-----------|----------------|-------------|-----------------------|---------------------|-----------------------------------|
| 101 Panel Front Door Outer           | 5.54      | 0.7/1.0        | 210         | Hydroformed Sheet     | Tailor Welded Blank | Hemmed to Inner, Adhesive Bonding |
| 100 Panel Front Door Inner           | 5.90      | 1.5/1.0/0.6    | 280/140/140 | Stamping              | Tailor Welded Blank | Hemmed to Outer                   |
| 102 Impact Beam Front Door           | 1.46      | 1.6            | 1200        | Rollformed            | Coil                | Spot Welding                      |
| 112/114 Reinf. Hinge Lower/Upper     | 0.12      | 2.0            | 140         | Stamping              | Coil                | Spot Welding, Adhesive Bonding    |
| Paint Allowance                      | 0.15      |                |             |                       |                     |                                   |
| Total Mass                           | 13.17     |                |             |                       |                     |                                   |
| Normalized Mass (kg/m <sup>2</sup> ) | 15.14     |                |             |                       |                     |                                   |
| Surface (m <sup>2</sup> )            | 0.87      |                |             |                       |                     |                                   |

## 6.1.2 Frame integrated



blank layout

hydroformed tube that forms the lower door frame withstands sag and check load stresses and incorporates the side intrusion beam to save mass. Improved stiffness is created by the continuous connection from the laser welding that is used to attach parts to the hydroformed frame. The frame concept allows better assembly accessibility and subsequent service of the window regulator, latch system and wiring harness.

### Design highlights

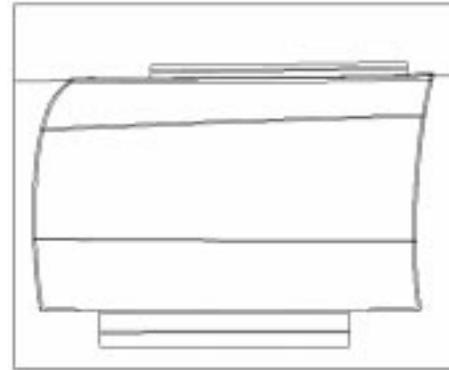
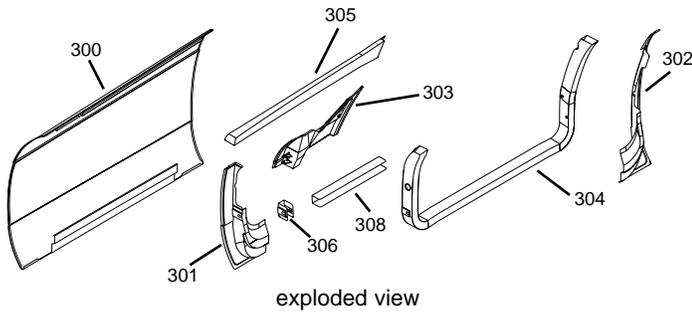
Sheet hydroforming and feature lines create the same benefits for dent resistance in the frame integrated door as in the roof integrated door. The high strength steel

This design results in the creation of a structure with a normalized mass of 15.5 kg/m<sup>2</sup> compared with the target of 15.5 kg/m<sup>2</sup>. It is 21 percent lighter than the benchmarked average.

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material      | Joining Technology      |
|--------------------------------------|-----------|----------------|-------------|-----------------------|---------------------|-------------------------|
| 204 Panel Front Door Outer           | 5.27      | 0.7/1.0        | 210         | Sheet Hydroformed     | Tailor Welded Blank | Hemmed, Adhesive Bonded |
| 206 Panel Front Door Inner Front     | 0.47      | 0.6            | 140         | Stamping              | Coil                | Hemmed, Adhesive Bonded |
| 208 Panel Front Door Inner Rear      | 0.48      | 0.6            | 140         | Stamping              | Coil                | Hemmed                  |
| 200 Tube Door Frame Upr Front        | 1.20      | 0.8            | 140         | Rollformed            | Coil                | Laser Welded            |
| 202 Tube Door Frame Lwr Front        | 4.11      | 1.2            | 280         | Tube Hydroformed      | Tube                | Laser Welded            |
| 217 Reinforcement Beltline           | 0.66      | 1.0            | 350         | Stamping              | Coil                | Spot, Laser Welded      |
| 220 Reinforced Mirror Flag           | 0.17      | 0.7            | 140         | Stamping              | Coil                | Spot, Laser Welded      |
| 219 Reinforcement Impact Beam        | 0.48      | 1.2            | 1200        | Rollformed            | Coil                | Laser Welded            |
| 212 Reinforcement Upper Hinge        | 0.09      | 1.2            | 140         | Stamping              | Coil                | Laser Welded            |
| 214 Reinforcement Lower Hinge        | 0.09      | 1.2            | 140         | Stamping              | Coil                | Laser Welded            |
| Paint Allowance                      | 0.15      |                |             |                       |                     |                         |
| Total Mass                           | 13.17     |                |             |                       |                     |                         |
| Normalized Mass (kg/m <sup>2</sup> ) | 15.49     |                |             |                       |                     |                         |
| Surface (m <sup>2</sup> )            | 0.85      |                |             |                       |                     |                         |

### 6.1.3 Frameless



blank layout

#### Design highlights

Sheet hydroforming and feature lines create the same benefits for dent resistance in the frameless door as in the roof integrated and the frame integrated doors. The high strength steel hydroformed tube that forms the lower door frame withstands sag and checkload stresses and incorporates the side intrusion beam to save mass. The frame concept allows better assembly accessibility and subsequent service of the win-

dow regulator, latch system and wiring harness. A thin wall casting used as a structural node to connect the upper and lower frame saves mass by incorporating several features in one part, including the mirror patch, upper hinge and joint node.

This design results in the creation of a structure with a normalized mass of 14.3 kg/m<sup>2</sup> compared with the target of 15.5 kg/m<sup>2</sup>. It is 27 percent lighter than the benchmarked average.

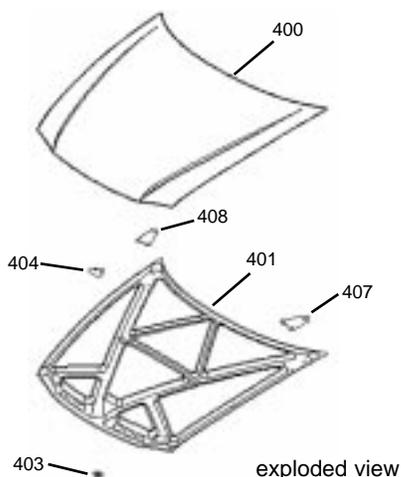
#### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material      | Joining Technology                |
|--------------------------------------|-----------|----------------|-------------|-----------------------|---------------------|-----------------------------------|
| 300 Panel Outer                      | 4.90      | 0.7/1.0        | 210         | Sheet Hydroformed     | Tailor Welded Blank | Hemmed, Adh. Bonded, Laser Welded |
| 301 Panel Inner Front                | 0.38      | 0.6            | 140         | Stamping              | Coil                | Hemmed, Adh. Bonded, Laser Welded |
| 302 Panel Inner Rear                 | 0.41      | 0.6            | 140         | Stamping              | Coil                | Hemmed, Adh. Bonded, Laser Welded |
| 304 Tube Door Frame Lower            | 3.21      | 1.2            | 280         | Tube Hydroformed      | Tube                | Laser Welded                      |
| 303 Bracket Remote Mirror            | 0.87      | 1.5            | 140         | Thin Wall Casting     | Ingot               | Laser Welded                      |
| 305 Reinforcement Beltline           | 1.06      | 0.8            | 350         | Tube Hydroformed      | Tube                | Laser Welded                      |
| 308 Reinforcement Impact Beam        | 0.40      | 1.0            | 1200        | Rollformed            | Coil                | Laser Welded                      |
| 306 Reinforcement Hinge Lower        | 0.09      | 1.2            | 140         | Stamping              | Coil                | Laser Welded                      |
| Paint Allowance                      | 0.15      |                |             |                       |                     |                                   |
| Total Mass                           | 11.47     |                |             |                       |                     |                                   |
| Normalized Mass (kg/m <sup>2</sup> ) | 14.34     |                |             |                       |                     |                                   |
| Surface (m <sup>2</sup> )            | 0.80      |                |             |                       |                     |                                   |

## 6.2 Hood

In conducting this study, PES's first objective was to reach the aggressive mass target of 10 percent below the benchmarked best-in-class. This was a difficult goal for hood designs since the benchmarked closures are already efficient steel structures. In the initial study, PES proposed progressive designs using steel sandwich material to reach mass targets. Given that steel sandwich material is not yet widely used in large production quantities and is more costly, PES recommended an alternative 0.6mm sheet steel for manufacturing inner panels. This alternative demonstrates performance results that are similar to the sandwich material at reduced cost, but with a slight sacrifice to mass savings.

### 6.2.1 Conventional



#### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa)     | Manufacturing Process | Stock Material | Joining Technology                    |
|--------------------------------------|-----------|----------------|-----------------|-----------------------|----------------|---------------------------------------|
| 400 Panel Hood Outer                 | 8.14      | 0.6            | 210             | Sheet Hydroformed     | Coil           | Hemmed, Adhesive Bonded               |
| 401 Panel Hood Inner                 | 4.39      | 1.2            | Steel Sandwich* | Stamping              | Sheet          | Hemmed, Adhesive Bonded               |
| 403 Striker Assembly Hood            | 0.07      | 2.5            | 140             | Stamping              | Coil           | Bolt-on                               |
| 404 Reinforcement Striker            | 0.07      | 1.5            | 140             | Stamping              | Coil           | Adhesive Bonded, Self Pierce Riveting |
| 407/408 Reinf. Hinge LH/RH Hood      | 0.31      | 1.5            | 140             | Stamping              | Coil           | Adhesive Bonded, Self Pierce Riveting |
| Paint & Gumdrops                     | 0.35      |                |                 |                       |                |                                       |
| Total Mass                           | 13.33     |                |                 |                       |                |                                       |
| Normalized Mass (kg/m <sup>2</sup> ) | 7.93      |                |                 |                       |                |                                       |
| Surface (m <sup>2</sup> )            | 1.68      |                |                 |                       |                |                                       |

| *Alternative sheet steel concept |                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) |
|----------------------------------|--------------------------------------|-----------|----------------|-------------|
|                                  | 401 Panel Hood Inner                 | 5.33      | 0.6            | 140         |
|                                  | Total Mass                           | 14.27     |                |             |
|                                  | Normalized Mass (kg/m <sup>2</sup> ) | 8.49      |                |             |
|                                  | Surface (m <sup>2</sup> )            | 1.68      |                |             |

## Design highlights

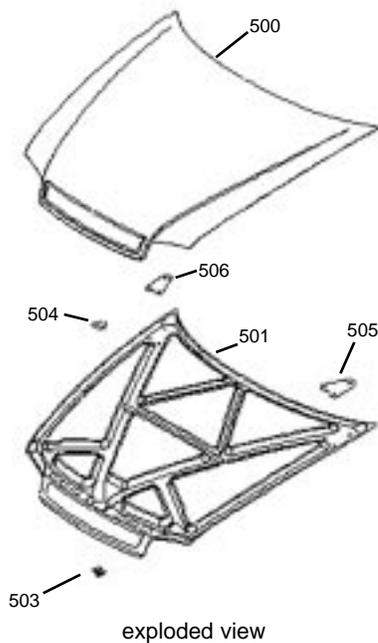
This design employs a 0.6 mm sheet hydroformed outer panel and feature lines to improve dent resistance in the thin material. Adhesive bonding is used in the hem flanges for structural performance. To improve stiffness, a 'V' pattern inner panel connects the hinges to the latch area, and a hole — not a depression — is used as a crush initiator in the side beam. Triangular beams designed within the 'V' pattern support the outer panel.

Steel sandwich material is used in the inner panel for mass reduction. This material consists of a 0.8 mm engineered polypropylene core sandwiched between two 0.2 mm sheets of steel. It can withstand bake ovens and can be assembled prior to painting.

This design results in the creation of a structure with a normalized mass of 7.9 kg/m<sup>2</sup> compared with the target of 8.0 kg/m<sup>2</sup>. It is 32 percent lighter than the benchmarked average.

As mentioned in this section's introduction, PES recommended a 0.6 mm sheet steel inner panel as an alternative to more costly sandwich material. This concept demonstrates performance results that are similar to the sandwich material concept but has a normalized mass of 8.5 kg/m<sup>2</sup> compared with the target of 8.0 kg/m<sup>2</sup>. It is 26 percent lighter than the benchmarked average.

## 6.2.2 Grille integrated



### Design highlights

This design concept is similar to the conventional with the addition of a grille formed by extending the inner and outer panels. It employs a sheet hydroformed outer panel and feature lines to improve dent resistance in the thin material. Adhesive bonding is used in the hem flanges for structural performance. To improve stiffness, a ‘V’ pattern connects the

hinges to the latch area and a hole — not a depression — is used as a crush initiator in the side beam. Triangular beams designed within the ‘V’ pattern support the outer panel.

Steel sandwich material is used in the inner panel for mass reduction. This material consists of a 0.8 mm engineered polypropylene core sandwiched between two 0.2 mm sheets of steel. It can withstand bake ovens and can be assembled prior to painting.

This design results in the creation of a structure with a normalized mass of 7.9 kg/m<sup>2</sup> compared with its target of 8.0 kg/m<sup>2</sup>. It is 32 percent lighter than the benchmarked average.

As mentioned in this section’s introduction, PES recommended a 0.6 mm sheet steel inner panel as an alternative to more costly sandwich material. This concept demonstrates performance results that are similar to the sandwich material concept but has a normalized mass of 8.4 kg/m<sup>2</sup> compared with the target of 8.0 kg/m<sup>2</sup>. It is 27 percent lighter than the benchmarked average.

(The normalized mass of the grille integrated is less than the normalized mass of the conventional hood because its increased surface area results in a larger denominator in the normalization equation.)

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa)     | Manufacturing Process | Stock Material | Joining Technology                    |
|--------------------------------------|-----------|----------------|-----------------|-----------------------|----------------|---------------------------------------|
| 500 Panel Hood Outer                 | 8.37      | 0.6            | 210             | Sheet Hydroformed     | Coil           | Hemmed, Adhesive Bonded               |
| 501 Panel Hood Inner                 | 4.53      | 1.2            | Steel Sandwich* | Stamping              | Sheet          | Hemmed, Adhesive Bonded               |
| 503 Striker Assembly Hood            | 0.07      | 2.5            | 140             | Stamping              | Coil           | Bolt-on                               |
| 504 Reinforcement Striker Hood       | 0.05      | 1.5            | 140             | Stamping              | Coil           | Adhesive Bonded, Self-Pierce Riveting |
| 505/506 Reinf. Hinge RH/LH Hood      | 0.31      | 1.5            | 140             | Stamping              | Coil           | Adhesive Bonded, Self-Pierce Riveting |
| Paint & Gumdrops                     | 0.35      |                |                 |                       |                |                                       |
| Total Mass                           | 13.68     |                |                 |                       |                |                                       |
| Normalized Mass (kg/m <sup>2</sup> ) | 7.86      |                |                 |                       |                |                                       |

Surface (m<sup>2</sup>) 1.74

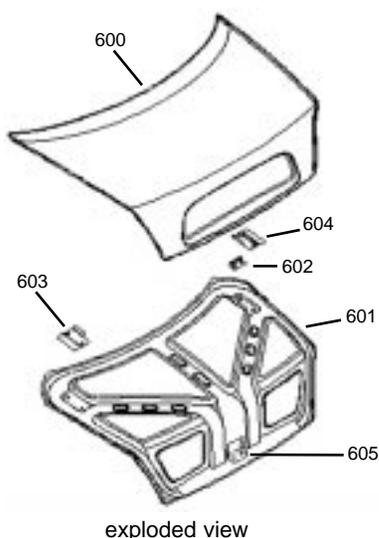
| *Alternative sheet steel concept     | Mass (kg) | Thickness (mm) | Grade (Mpa) |
|--------------------------------------|-----------|----------------|-------------|
| 501 Panel Hood Inner                 | 5.52      | 0.6            | 140         |
| Total Mass                           | 14.67     |                |             |
| Normalized Mass (kg/m <sup>2</sup> ) | 8.43      |                |             |

Surface (m<sup>2</sup>) 1.74

### 6.3 Decklid

Similar to the approach taken in developing hood designs, PES sought to reach an aggressive mass target of 10 percent below the benchmarked best-in-class in creating decklid designs. As with hoods, initial concepts used steel sandwich material to achieve mass savings. As an alternative to the higher cost steel sandwich material, PES recommended the use of 0.6 mm sheet steel in manufacturing the inner panel. Again, this alternative demonstrates performance results that are similar to the sandwich material at reduced cost, but with a slight sacrifice to mass savings.

#### 6.3.1 Conventional with tail



#### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa)     | Manufacturing Process | Stock Material | Joining Technology                    |
|--------------------------------------|-----------|----------------|-----------------|-----------------------|----------------|---------------------------------------|
| 600 Panel Decklid Outer              | 5.80      | 0.6            | 210             | Sheet Hydroformed     | Coil           | Hemme Adhesive Bonded                 |
| 601 Panel Decklid Inner              | 3.27      | 1.2            | Steel Sandwich* | Stamping              | Sheet          | Hemmed, Adhesive Bonded               |
| 602 Striker Assembly Decklid         | 0.07      | 1.5            | 140             | Stamping              | Coil           | Bolt-on                               |
| 603/604 Reinf. Hinge LH/RH Decklid   | 0.32      | 1.2            | 140             | Stamping              | Coil           | Adhesive Bonded, Self-Pierce Riveting |
| 605 Reinforcement Striker Decklid    | 0.04      | 1.5            | 140             | Stamping              | Coil           | Adhesive Bonded, Self-Pierce Riveting |
| Paint & Gumdrops                     | 0.35      |                |                 |                       |                |                                       |
| Total Mass                           | 9.85      |                |                 |                       |                |                                       |
| Normalized Mass (kg/m <sup>2</sup> ) | 8.00      |                |                 |                       |                |                                       |

Surface (m<sup>2</sup>) 1.23

| *Alternative sheet steel concept     | Mass (kg) | Thickness (mm) | Grade (Mpa) |
|--------------------------------------|-----------|----------------|-------------|
| 601 Panel Decklid Inner              | 3.99      | 0.6            | 140         |
| Total Mass                           | 10.57     |                |             |
| Normalized Mass (kg/m <sup>2</sup> ) | 8.59      |                |             |

Surface (m<sup>2</sup>) 1.23

#### Design highlights

This design concept employs a sheet hydroformed outer panel to improve dent resistance in the thin material. Adhesive bonding is used in the hem flanges for structural performance. To improve stiffness, PES specified a 'V' pattern inner panel to connect the hinges to the latch area; specified down standing flange on both sides; and formed the license plate pocket from the outer panel.

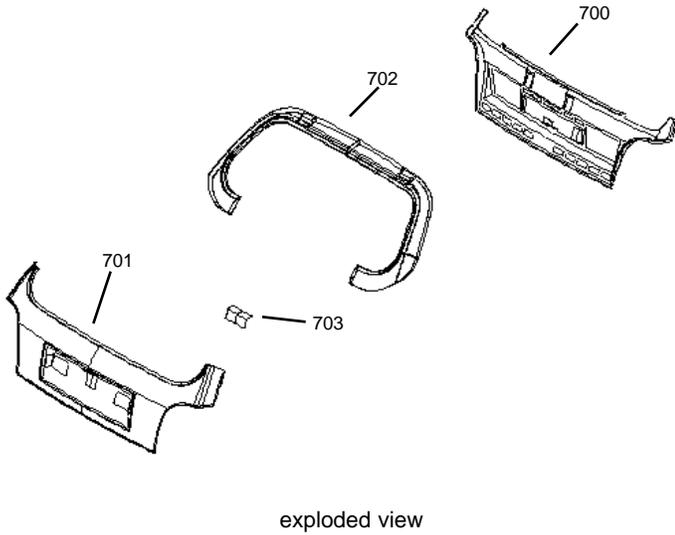
Steel sandwich material is used in the inner panel for mass reduction. This material consists of a 0.8 mm engineered polypropylene core sandwiched between two 0.2 mm sheets of steel. It can withstand bake ovens and can be assembled prior to painting.

This design results in the creation of a structure with a normalized mass of 8.0 kg/m<sup>2</sup> exactly meeting the target of 8.0 kg/m<sup>2</sup>. It is 29 percent lighter than the benchmarked average.

As mentioned in this section's introduction, PES recommended a 0.6 mm sheet steel inner panel as an alternative to more costly sandwich material. This concept demonstrates performance results that are similar to the sandwich material concept but has a normalized mass of 8.6 kg/m<sup>2</sup> compared with the target of 8.0 kg/m<sup>2</sup>. It is 23 percent lighter than the benchmarked average.

## 6.4 Hatch

### 6.4.1 Lift Gate Type — Tube Hydroformed



### Design highlights

This design features a hydroformed tube hatch, laser welded to a conventional inner. A sheet hydroformed outer is then hemmed to the inner panel. The tube hydroforming and assembly process lend inherent integrity to the hatch, while sheet hydroforming provides excellent dent resistance at a thinner gauge.

This design results in the creation of a structure with a normalized mass of 10.3 kg/m<sup>2</sup> compared with the target of 11.3 kg/m<sup>2</sup>. It is 26 percent lighter than the benchmarked average.

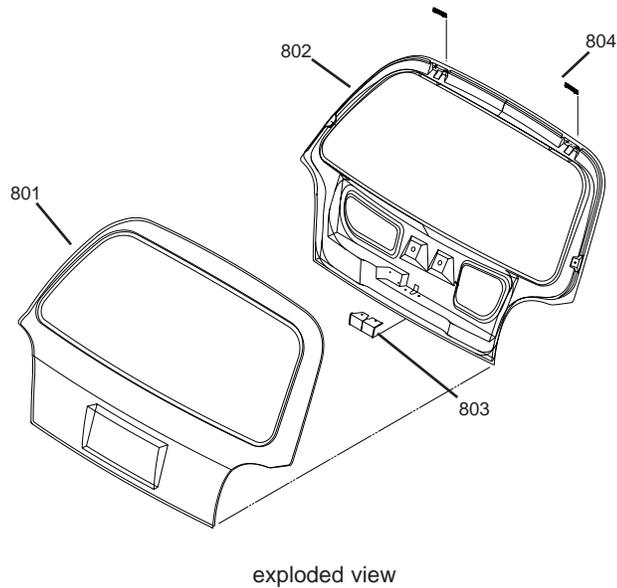
Due to the more complex manufacturing process, this design was slightly above cost baseline targets. For this reason, PES explored alternatives, which resulted in three additional concepts: tailored blank inner, hydroformed ring and sheet hydroformed hatches. The results of these additional concepts are discussed in Sections 6.4.2-6.4.4 following.

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material | Joining Technology                    |
|--------------------------------------|-----------|----------------|-------------|-----------------------|----------------|---------------------------------------|
| 701 Panel Hatchback Outer            | 1.86      | 0.6            | 210         | Sheet Hydroformed     | Coil           | Hemmed, Adhesive Bonded, Laser Welded |
| 700 Panel Hatchback Inner            | 1.69      | 0.6            | 140         | Stamping              | Coil           | Hemmed, Adhesive Bonded, Laser Welded |
| 702 Tube Hatchback                   | 2.89      | 0.7            | 140         | Tube Hydroformed      | Tube           | Laser Welded                          |
| 703 Reinf. Latch Hatchback           | 0.12      | 1.5            | 140         | Stamping              | Coil           | Spot Welded                           |
| Paint Allowance                      | 0.15      |                |             |                       |                |                                       |
| Total Mass                           | 6.71      |                |             |                       |                |                                       |
| Normalized Mass (kg/m <sup>2</sup> ) | 10.32     |                |             |                       |                |                                       |
| Surface (m <sup>2</sup> )            | 0.65      |                |             |                       |                |                                       |

## 6.4 Hatch

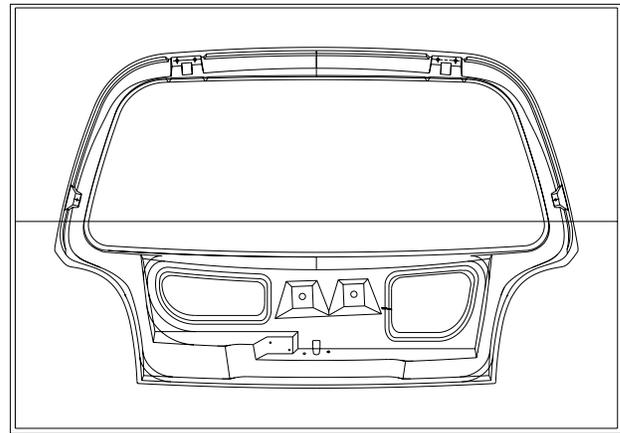
### 6.4.2 Lift Gate Type — Tailored Blank Inner



### Design highlights

In this design, a sheet hydroformed outer is hemmed to a stamped tailored blank inner panel. It provides a lower cost alternative to the tube hydroformed design, while meeting or exceeding mass and performance targets.

The design results in the creation of a structure with a normalized mass of 10.6 kg/m<sup>2</sup> compared with the target of 11.3 kg/m<sup>2</sup>. It is 24 percent lighter than the benchmarked average.

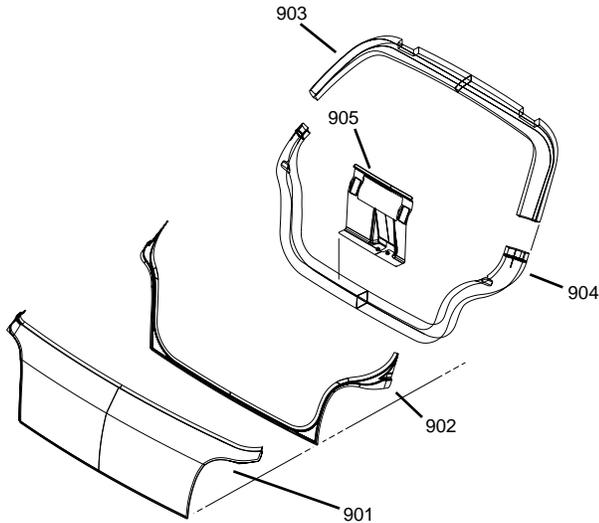


### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material | Joining Technology                    |
|--------------------------------------|-----------|----------------|-------------|-----------------------|----------------|---------------------------------------|
| 801 Panel Hatchback Outer            | 3.28      | 0.6            | 210         | Sheet Hydroformed     | Coil           | Hemmed, Adhesive Bonded, Laser Welded |
| 802 Panel Hatchback Inner            | 3.02      | 0.6/0.8        | 140         | Stamping              | Tailored Blank | Hemmed, Adhesive Bonded, Laser Welded |
| 803 Reinf. Latch Hatchback           | 0.12      | 1.5            | 140         | Stamping              | Coil           | Spot Welded                           |
| 804 Reinf. Hinge Upper               | 0.32      | 1.5            | 140         | Stamping              | Coil           | Spot Welded                           |
| Paint Allowance                      | 0.15      |                |             |                       |                |                                       |
| Total Mass                           | 6.89      |                |             |                       |                |                                       |
| Normalized Mass (kg/m <sup>2</sup> ) | 10.60     |                |             |                       |                |                                       |
| Surface (m <sup>2</sup> )            | 0.65      |                |             |                       |                |                                       |

## 6.4 Hatch

### 6.4.3 Lift Gate Type — Hydroformed Ring



exploded view

### Design highlights

The hydroformed ring design specifies a complete tubular hydroformed frame, eliminating the necessity of a full inner panel. The ring provides intrinsic structural integrity, while saving mass.

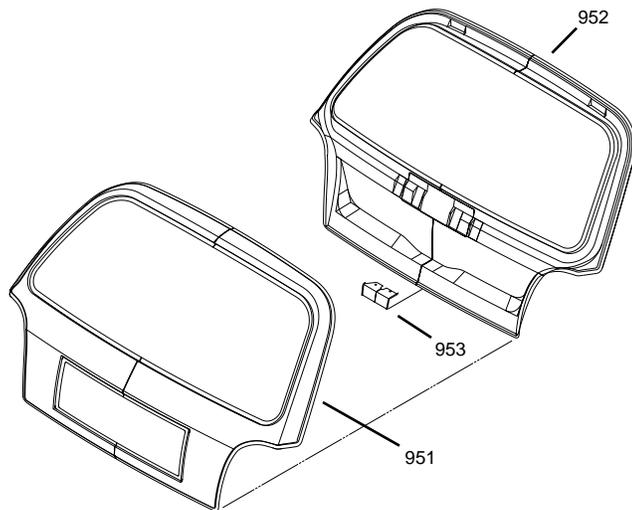
This design results in the creation of a structure with a normalized mass of 10.9 kg/m<sup>2</sup> compared with the target of 11.3 kg/m<sup>2</sup>. It is 22 percent lighter than the benchmarked average. Due to the very stiff nature of this design approach, further mass reduction will be achievable through additional design development.

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material | Joining Technology        |
|--------------------------------------|-----------|----------------|-------------|-----------------------|----------------|---------------------------|
| 901 Panel Hatchback Outer            | 2.04      | 0.6            | 210         | Sheet Hydroformed     | Coil           | Hemmed                    |
| 902 Panel Hatchback Inner            | 0.39      | 0.6            | 140         | Stamping              | Coil           | Laser Welded              |
| 903 Tube Hatchback Upper             | 1.85      | 0.7            | 140         | Tube Hydroformed      | Tube           | Laser Welded              |
| 904 Tube Hatchback Lower             | 2.23      | 0.7            | 140         | Tube Hydroformed      | Tube           | Laser Welded              |
| 905 Bracket Hatchback                | 0.44      | 0.6            | 140         | Stamping              | Coil           | Laser Welded, Spot Welded |
| Paint Allowance                      | 0.15      |                |             |                       |                |                           |
| Total Mass                           | 7.10      |                |             |                       |                |                           |
| Normalized Mass (kg/m <sup>2</sup> ) | 10.92     |                |             |                       |                |                           |
| Surface (m <sup>2</sup> )            | 0.65      |                |             |                       |                |                           |

## 6.4 Hatch

### 6.4.4 Lift Gate Type — Sheet Hydroformed



exploded view

### Design highlights

A conceptual design that creates stiffness at considerable mass savings is achieved with a sheet hydroforming process. A continuous laser weld is used to join inner and outer panels providing a fluid pressure seal for the hydroforming process. In this process, internal forming pressure expands the parts into the molds. The sheet hydroforming process contributes further to local panel stiffness through work hardening of the inner and outer panels. To contribute to torsional stiffness, the glass is bonded to the frame using urethane.

This design results in the creation of a structure with a normalized mass of 9.5 kg/m<sup>2</sup> compared with the target of 11.3 kg/m<sup>2</sup>. It is 32 percent lighter than the benchmarked average.

This is a preliminary concept that appears to offer a feasible alternative to lift gate design, but requires further PES examination to prove its feasibility.

### Specifications

|                                      | Mass (kg) | Thickness (mm) | Grade (Mpa) | Manufacturing Process | Stock Material | Joining Technology |
|--------------------------------------|-----------|----------------|-------------|-----------------------|----------------|--------------------|
| 951 Panel Hatchback Outer            | 3.10      | 0.6            | 210         | Sheet Hydroformed     | Coil           | Laser Welded       |
| 952 Panel Hatchback Inner            | 2.83      | 0.6            | 140         | Sheet Hydroformed     | Coil           | Laser Welded       |
| 953 Reinf. Latch Hatchback           | 0.12      | 1.5            | 140         | Stamping              | Coil           | Spot Welded        |
| Paint Allowance                      | 0.15      |                |             |                       |                |                    |
| Total Mass                           | 6.20      |                |             |                       |                |                    |
| Normalized Mass (kg/m <sup>2</sup> ) | 9.54      |                |             |                       |                |                    |
| Surface (m <sup>2</sup> )            | 0.65      |                |             |                       |                |                    |

## 7. FEA Calculations

Throughout the design process, FEA calculations were run on each part to confirm the effectiveness of the latest optimizations and to validate the concepts. FEA models were all shell and very detailed. Spot welds, laser welds and structural adhesives were represented using rigid elements. Gum drops were represented using spring elements with stiffnesses in three directions. Adhesive bonded hem flanges were treated as continuous connections with shell element thickness comprehending material stack up. Hinges were considered rigid so that only compliance of closures was analyzed. All models were run using MSC/NASTRAN. A linear static solution was used for stiffness and strength load cases. A free-free linear dynamic solution was used for normal mode analysis to ensure that the normal mode frequencies of the closures would not couple with the frequencies of the body structure. LS Dyna 3D was used for nonlinear door side intrusion and longitudinal door crush simulations.

### 7.1 Door

The FEA model size for doors ranges in number of elements from 7,200 to 23,159 and number of nodes from 7,219 to 23,307. These ranges reflect the varying degree of detail in the three door concepts. Structural performance analyses include frame rigidity (except for frameless door), door sag, torsional rigidity and check load. To determine frame rigidity, the door was constrained at the hinges and rear and the door frame was loaded outboard front and rear independently. For door sag, the door was constrained at the hinges and loaded vertically at the latch. To determine torsional rigidity the door was constrained at the hinges and latch while the door was loaded top and bottom at rear to apply torque. For check load, the door was constrained at the hinges with the door in full open position and loaded outboard against the latch. This is an abuse load for which peak stresses are recovered to determine whether permanent deformation would occur. All

door designs met structural performance targets, except in the case of the frame rigidity rear target for the roof integrated design. It did not meet target because rear package constraints prevent the efficient use of material at the belt. An OEM survey showed this result would be acceptable to most automakers. The frame integrated design's rolled section upper frame enabled it to perform especially well in frame rigidity load cases. The frameless design exhibited the best result of the three in door sag. This performance is due mainly to the thin wall casting.

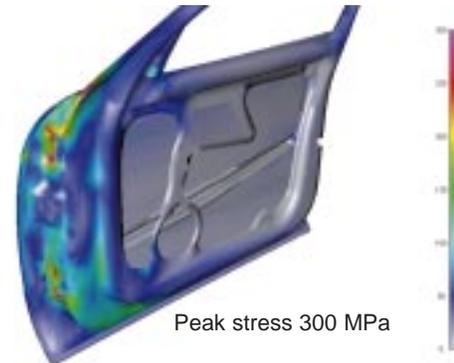
To predict side impact performance, PES subjected the door to a side intrusion load case. First, the side intrusion beams in the model were situated where FMVSS 214 specifies their placement. Then the door was constrained at the hinges and latch and loaded inboard. Only the first six inches of intrusion were simulated due to the lack of door surround definition. The analysis results exceed standards set forth in FMVSS requirement 214.

To judge performance of the door concept during an offset crash, without the use of a full vehicle crash model, a procedure was employed which treats the door as an integrated system. The procedure comprised an idealized longitudinal crush with the door constrained at the hinges, and the door rear loaded until buckling failure occurred. The performance observed for all ULSAC doors would be acceptable to most automakers.

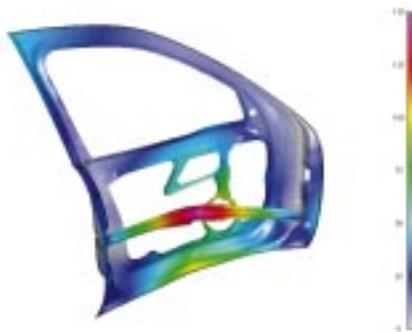
## 7.1.1 Roof integrated

### Structural performance

| Load case                | Target (N/mm) | Actual (N/mm) |
|--------------------------|---------------|---------------|
| Frame rigidity front     | ≥ 43          | 45            |
| Frame rigidity rear      | ≥ 43          | 38            |
| Door sag                 | ≥ 287         | 318           |
| Torsional rigidity upper | ≥ 94          | 272           |
| Torsional rigidity lower | ≥ 94          | 146           |



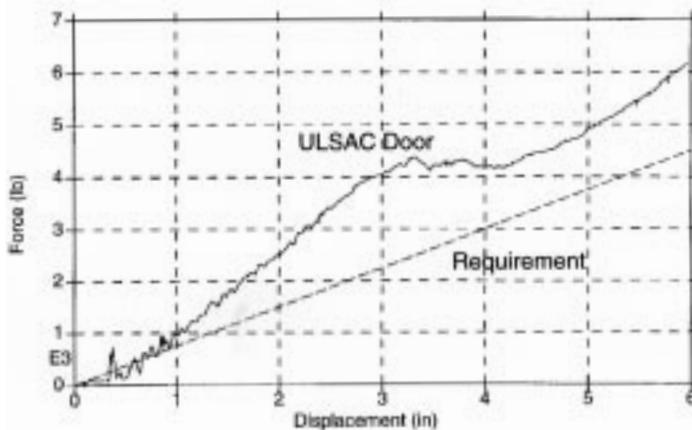
Check load



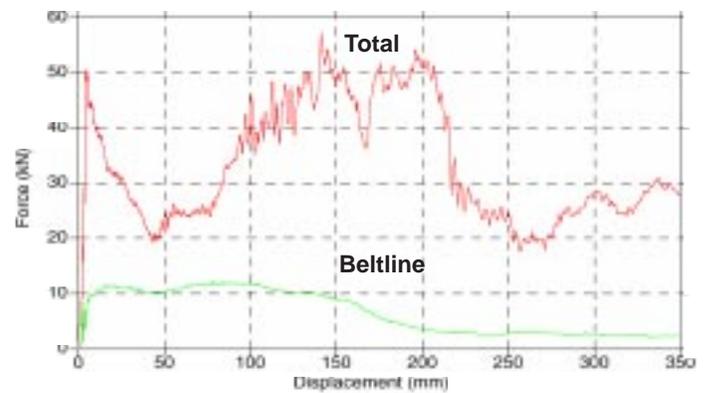
Side intrusion



Longitudinal Door Crush



Load Deflection - Side Intrusion

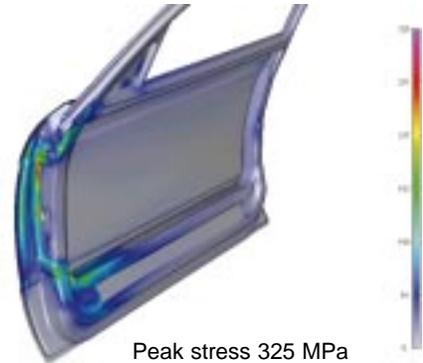


Load Deflection - Door Crush

## 7.1.2 Frame integrated

Structural performance

| Load case                | Target (N/mm) | Actual (N/mm) |
|--------------------------|---------------|---------------|
| Frame rigidity front     | ≥ 43          | 64            |
| Frame rigidity rear      | ≥ 43          | 52            |
| Door sag                 | ≥ 287         | 299           |
| Torsional rigidity upper | ≥ 94          | 155           |
| Torsional rigidity lower | ≥ 94          | 107           |



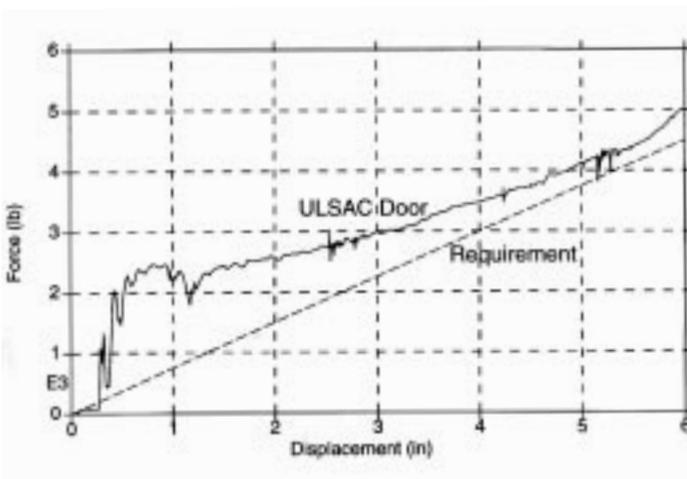
Check load



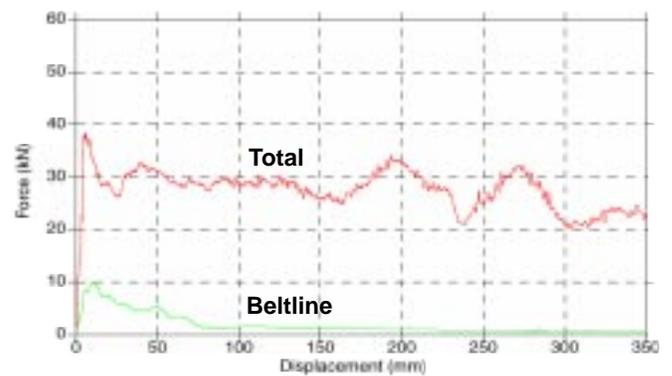
Side intrusion



Longitudinal Door Crush



Load deflection - Side Intrusion



Load Deflection - Door Crush

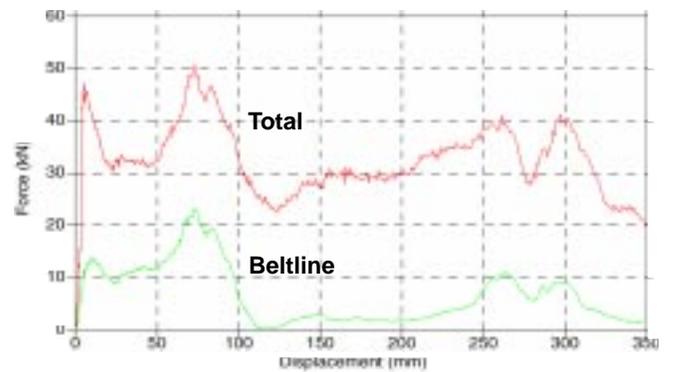
### 7.1.3 Frameless

Structural performance

| Load case                | Target (N/mm) | Actual (N/mm) |
|--------------------------|---------------|---------------|
| Door sag                 | $\geq 287$    | 346           |
| Torsional rigidity upper | $\geq 94$     | 170           |
| Torsional rigidity lower | $\geq 94$     | 117           |



Longitudinal Door Crush



Load Deflection - Door Crush

## 7.2 Hood

The FEA model size for hoods ranges in number of elements from 11,164 to 13,359 and number of nodes from 12,251 to 12,416. Structural performance data include torsional rigidity, bending stiffness and beam stiffnesses. To determine torsional rigidity, the hood was constrained at the hinges and at one of the front bump stops while loaded vertically at the unconstrained bump stop. For bending stiffness, the hood was constrained at the hinges while the load was applied at the front edge. To determine side beam stiffnesses, the hood was constrained at the hinges and bump stops while vertical loads were applied independently at each side beam at the centerline of the section.

### 7.2.1 Conventional

Structural performance

| Load case            | Target (N/mm) | Actual (N/mm) |
|----------------------|---------------|---------------|
| Torsional rigidity   | ≥ 5.8         | 6.3           |
| Bending stiffness    | ≥ 4.5         | 7.2           |
| Front beam stiffness | ≥ 110         | 186           |
| Rear beam stiffness  | ≥ 110         | 286           |
| Side beam stiffness  | ≥ 110         | 136           |

This closure met all structural performance targets.

### 7.2.2 Grille integrated

Structural performance

| Load case            | Target (N/mm) | Actual (N/mm) |
|----------------------|---------------|---------------|
| Torsional rigidity   | ≥ 5.8         | 6.6           |
| Bending stiffness    | ≥ 4.5         | 7.4           |
| Front beam stiffness | ≥ 110         | 195           |
| Rear beam stiffness  | ≥ 110         | 282           |
| Side beam stiffness  | ≥ 110         | 137           |

This closure shows results similar to the conventional hood and meets all structural performance targets.

## 7.3 Decklid

The FEA model size for the decklid included 10,006 elements and 9,053 nodes. Structural performance data for the decklid encompasses torsional rigidity, bending stiffness, beam stiffnesses and tail stiffness. To determine torsional rigidity, the decklid was constrained at the hinges and one of the rear bump stops while it was loaded vertically at the unconstrained bump stop. For bending stiffness, the decklid was constrained at the hinges and loaded vertically at the rear edge on centerline. To determine side beam stiffnesses, the decklid was constrained at the hinges and bump stops while vertical loads were applied independently at each side beam at the centerline of the section. For tail stiffness, the decklid was constrained at the hinges and bump stops while the load was applied forward at the lower rear edge on centerline.

### 7.3.1 Decklid

Structural performance

| Load case            | Target (N/mm) | Actual (N/mm) |
|----------------------|---------------|---------------|
| Torsional rigidity   | ≥ 5.8         | 8.9           |
| Bending stiffness    | ≥ 4.5         | 25.4          |
| Front beam stiffness | ≥ 110         | 115           |
| Side beam stiffness  | ≥ 110         | 147           |
| Tail stiffness       | ≥ 21          | 21            |

This closure demonstrates especially good bending stiffness because the reinforced hinge attachment at the inner panel transfers the load into the sheer wall of the inner panel section. Bending stiffness is also enhanced by the vertically downturned flange, which adds stiffness.

## 7.4 Hatch

The FEA model size for the hatch ranges in number of elements from 20,792 to 22,395 and number of nodes from 20,794 to 21,364. Structural performance data encompasses torsional rigidity and bending stiffness. To determine torsional rigidity the hatch was constrained at the hinges and at one of the rear bump stops while it was loaded vertically at the unconstrained bump stop. For bending stiffness the hatch was constrained at the hinges while the load was applied vertically at the rear edge on centerline.

### 7.4.1 Hatch — Tube Hydroformed

Structural performance

| Load case          | Target (N/mm) | Actual (N/mm) |
|--------------------|---------------|---------------|
| Torsional rigidity | ≥ 3.5         | 40            |
| Bending stiffness  | ≥ 4.5         | 31            |

This design concept uses a unique tubular hydroformed frame that provides a continuous load path, resulting in impressive rigidity and stiffness numbers.

### 7.4.2 Hatch — Tailored Blank

Structural performance

| Load case          | Target (N/mm) | Actual (N/mm) |
|--------------------|---------------|---------------|
| Torsional rigidity | ≥ 3.5         | 15.1          |
| Bending stiffness  | ≥ 4.5         | 8.2           |

Tailored blank design provides a more traditional manufacturing process with reduced part count, while maintaining acceptable performance.

### 7.4.3 Hatch — Hydroformed Ring

No FEA calculations were made in this concept phase. This is a preliminary concept that appears to offer a feasible alternative to lift gate designs, but requires further PES examination to prove its feasibility.

### 7.4.4 Hatch — Sheet Hydroformed

No FEA calculations were made in this concept phase. This is a preliminary concept that appears to offer a feasible alternative to lift gate designs, but requires further PES examination to prove its feasibility.

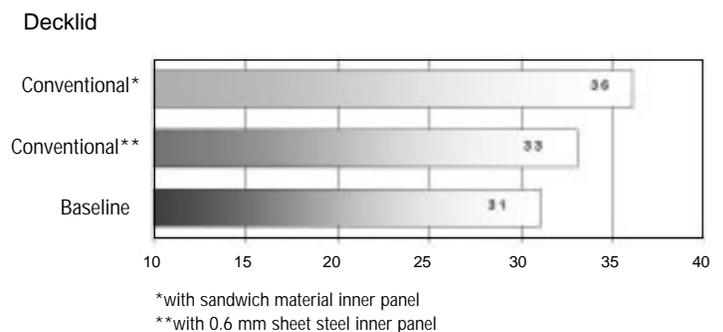
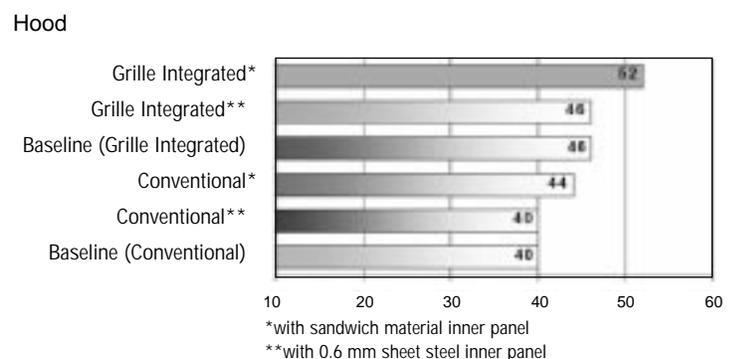
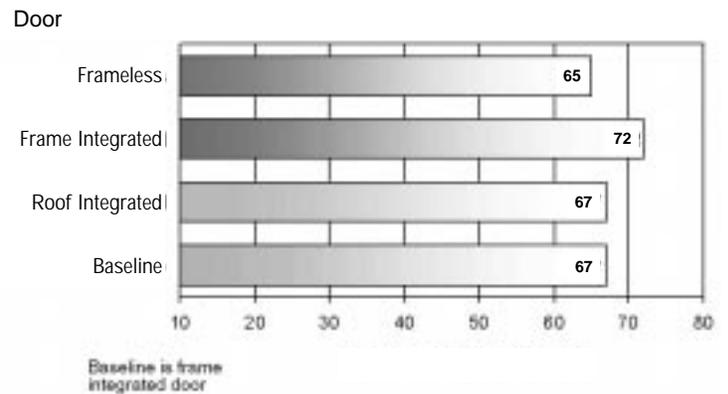
## 8. Cost Estimation

Lightweighting increasingly has become a priority for automakers. They have recently demonstrated their willingness to pay a premium for lightweight solutions that enable them to meet automotive weight requirements. Automakers reveal that they routinely pay up to twice as much for alternative lightweight closures. ULSAC balances light weight with affordable cost.

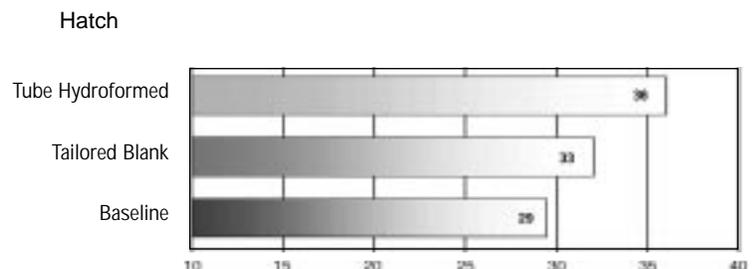
PES performed a cursory cost analysis of each of the closure concepts it developed for the ULSAC project. To create a baseline with which to compare ULSAC closures, PES developed cost estimates for current closures similar in material, size and geometry. Then PES estimated the cost of the concept based on manufacturing experience and knowledge of business economics.

For the doors, this economic analysis showed no cost penalty to a seven percent increase in the costs of the concept compared to baseline. For hoods, it found no additional cost over baseline for the sheet steel solution and an increase of about 10 percent for the steel sandwich design. Likewise, for decklids, the study revealed a six percent increase compared with baseline for the sheet steel solution and about a 16 percent increase for the steel sandwich design. Costs for the concept tube hydroformed hatch came in at approximately 24 percent above baseline due to the costly manufacturing process. The tailored blank inner design could be achieved at a cost only slightly above the aggressive baseline figure. As aforementioned, the hydroformed ring and sheet hydroformed designs are still in preliminary investigative stages, and consequently, no cost estimates are yet available. However, initial examination indicates that these two designs can effect results in the same range as the tailored blank design.

These economic analysis results are shown as follows:



Baseline is a conventional decklid



Baseline is a conventional decklid

Cost Estimation in Range  $\pm$  5%

## 9. Conclusion

ULSAC demonstrates steel closure concepts that are lightweight, structurally sound, manufacturable and affordable — workable, real world answers to the increasing challenges of lightweighting. ULSAC closures

- weigh up to 32 percent less than benchmarked averages

- weigh 10 percent less than best-in-class
- meet stringent structural performance targets
- can be fabricated using manufacturing processes and materials that are current and
- can cost no more to build than heavier closures.

### Door performance

|                  | Normalized Mass<br>kg/m <sup>2</sup> | Frame Rigidity |           | Torsional Rigidity |            | Door Sag<br>N/mm | Checkload<br>mm |
|------------------|--------------------------------------|----------------|-----------|--------------------|------------|------------------|-----------------|
|                  |                                      | Front N/mm     | Rear N/mm | Upper N/mm         | Lower N/mm |                  |                 |
| Targets          | 15.5                                 | > 43           | > 43      | ≥ 94               | ≥ 94       | 287.0            | ≤1.25 set       |
| Roof Integrated  | 15.1                                 | 45             | 38        | 272                | 146        | 318.0            | N/A             |
| Frame Integrated | 15.5                                 | 64             | 52        | 155                | 107        | 299.0            | N/A             |
| Frameless        | 14.3                                 | N/A            | N/A       | 170                | 117        | 346.0            | N/A             |

### Hood performance

|                                | Normalized Mass<br>kg/m <sup>2</sup> | Bending Stiffness<br>N/mm | Torsional Stiffness<br>N/mm | Beam Stiffness |           | Side Beam Stiffness |            |
|--------------------------------|--------------------------------------|---------------------------|-----------------------------|----------------|-----------|---------------------|------------|
|                                |                                      |                           |                             | Front N/mm     | Rear N/mm | Left N/mm           | Right N/mm |
| Targets                        | 8.0                                  | 4.5                       | 5.8                         | 110            | 110       | 110                 | 110        |
| Conventional Sandwich Inner    | 7.9                                  | 7.2                       | 6.3                         | 186            | 286       | 136                 | 136        |
| Grille Integrated Sandwich     | 7.9                                  | 7.4                       | 6.6                         | 195            | 282       | 137                 | 137        |
| Conventional Sheet Steel Inner | 8.5                                  | 4.7                       | 6.1                         | 161            | 276       | 152                 | 152        |
| Grille Integrated Steel Inner  | 8.4                                  | 4.8                       | 6.2                         | 181            | 273       | 156                 | 156        |

### Decklid performance

|                                | Normalized Mass<br>kg/m <sup>2</sup> | Bending Stiffness<br>N/mm | Torsional Stiffness<br>N/mm | Beam Stiffness<br>Front N/mm | Side Beam Stiffness |            | Tailgating<br>N/mm |
|--------------------------------|--------------------------------------|---------------------------|-----------------------------|------------------------------|---------------------|------------|--------------------|
|                                |                                      |                           |                             |                              | Left N/mm           | Right N/mm |                    |
| Targets                        | 8.0                                  | 4.5                       | 5.7                         | 110                          | 110                 | 110        | 21                 |
| Conventional Sandwich          | 8.0                                  | 25.4                      | 8.9                         | 115                          | 147                 | 147        | 21                 |
| Conventional Sheet Steel Inner | 8.6                                  | 24.0                      | 8.7                         | 115                          | 132                 | 132        | 19                 |

### Hatch performance

|                    | Normalized Mass<br>kg/m <sup>2</sup> | Bending Stiffness<br>N/mm | Torsional Stiffness<br>N/mm |
|--------------------|--------------------------------------|---------------------------|-----------------------------|
| Targets            | 11.3                                 | 4.5                       | 3.5                         |
| Tube Hydroformed   | 10.3                                 | 31.0                      | 40.0                        |
| Tailored Blank     | 10.6                                 | 8.2                       | 15.1                        |
| Hydroformed Ring*  | 10.9                                 | N/A                       | N/A                         |
| Sheet Hydroformed* | 9.5                                  | N/A                       | N/A                         |

\*Data not available.

### Mass Comparison

|                              | Benchmark (kg/m <sup>2</sup> ) |         | Target<br>(kg/m <sup>2</sup> ) | ULSAC                |      |
|------------------------------|--------------------------------|---------|--------------------------------|----------------------|------|
|                              | Range                          | Average |                                | (kg/m <sup>2</sup> ) | (kg) |
| Door - Roof Integrated       | 17.0 - 23.4                    | 19.7    | 15.5                           | 15.1                 | 13.2 |
| Door - Frame Integrated      |                                |         |                                | 15.5                 | 13.2 |
| Door - Frameless             |                                |         |                                | 14.3                 | 11.5 |
| Hood - Conventional*         | 8.8 - 14.2                     | 11.5    | 8.0                            | 7.9                  | 13.3 |
| Hood - Conventional**        |                                |         |                                | 8.5                  | 14.3 |
| Hood - Grille Integrated*    |                                |         |                                | 7.9                  | 13.7 |
| Hood - Grille Integrated**   |                                |         |                                | 8.4                  | 14.7 |
| Decklid Conventional*        | 8.9 - 16.1                     | 11.2    | 8.0                            | 8.0                  | 9.9  |
| Decklid Conventional**       |                                |         |                                | 8.6                  | 10.6 |
| Hatch - Tube Hydroformed     | 12.5 - 15.2                    | 13.9    | 11.3                           | 10.3                 | 6.7  |
| Hatch - Tailored Blank Inner |                                |         |                                | 10.6                 | 6.9  |
| Hatch - Hydroformed Ring     |                                |         |                                | 10.9                 | 7.1  |
| Hatch - Sheet Hydroformed    |                                |         |                                | 9.5                  | 6.2  |

\*with sandwich material inner panel

\*\*with 0.6 mm sheet steel inner panel

### Cost Comparison (U.S. \$)

|                              | Baseline                    | ULSAC |
|------------------------------|-----------------------------|-------|
| Door - Roof Integrated       | 67<br>Frame Integrated Door | 67    |
| Door - Frame Integrated      |                             | 72    |
| Door - Frameless             |                             | 65    |
| Hood - Conventional*         | 40                          | 44    |
| Hood - Conventional**        | 40                          | 40    |
| Hood - Grille Integrated*    | 46                          | 52    |
| Hood - Grille Integrated**   | 46                          | 46    |
| Decklid - Conventional*      | 31                          | 36    |
| Decklid - Conventional**     | 31                          | 33    |
| Hatchback - Tube Hydroformed | 29                          | 36    |
| Hatchback - Tailored Blank   | 29                          | 33    |

\*with sandwich material inner panel

\*\*with 0.6 mm sheet steel inner panel

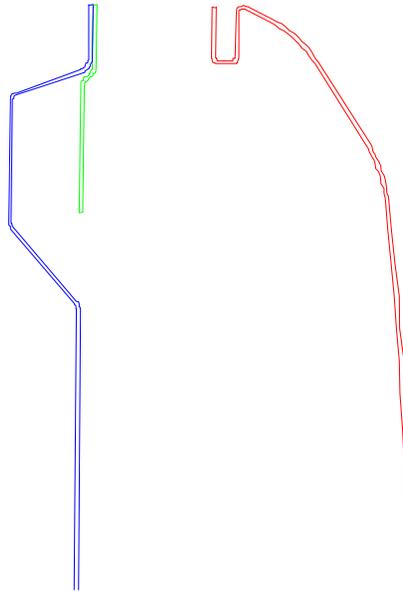


# Benchmarking

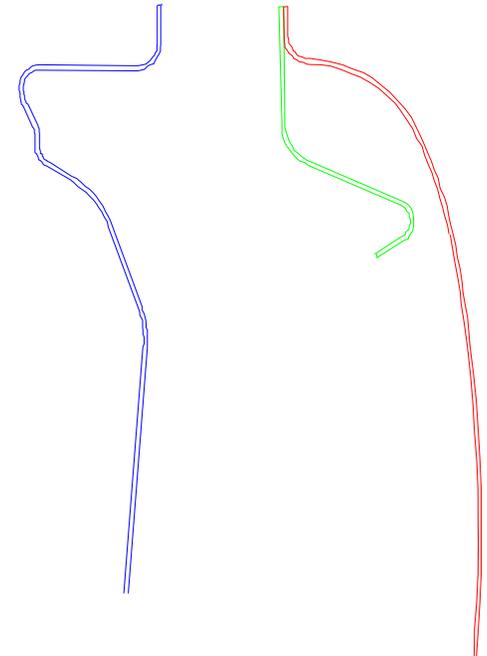
## *Data Gathering - Design Evaluation Typical Sections - Door - Beltline*



Inner & outer belt reinforcement



Inner belt reinforcement



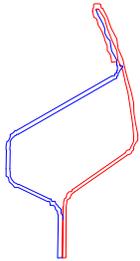
Outer belt reinforcement



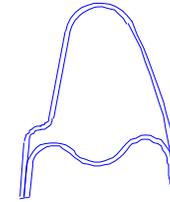


# Benchmarking

## *Data Gathering - Design Evaluation Typical Sections - Door - Frame*



Frame into roof inner & outer panel form section



Frame integral, inner & outer panel form section



Roll formed section



Extruded aluminum section



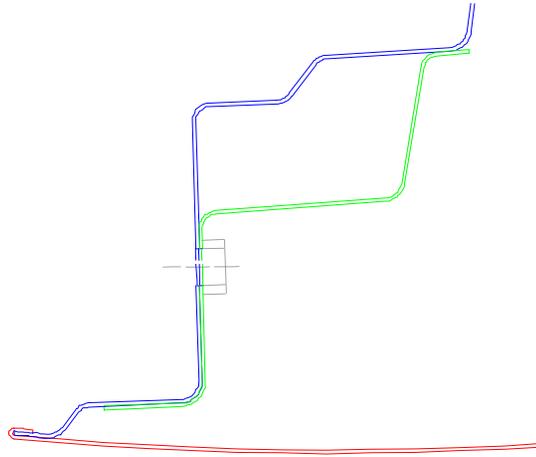


# Benchmarking

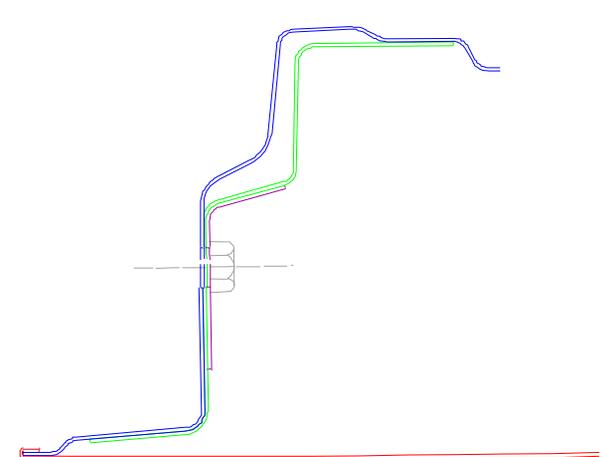
## *Data Gathering - Design Evaluation Typical Sections - Door - Hinge*



Tailor blanked inner panel



Reinforcement provides additional section



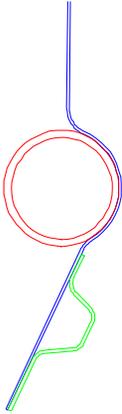
Reinforcement essentially doubles inner panel metal



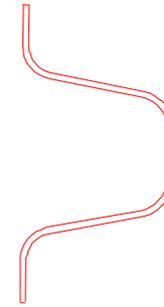


## Benchmarking

### **Data Gathering - Design Evaluation Typical Sections - Door - Crash Beam**



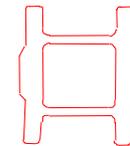
Tube provides good resistance to bending with a small package but constant section



Hat section



Double hat section



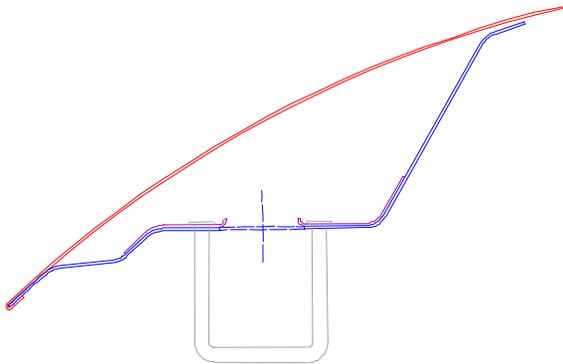
Extruded aluminum constant section



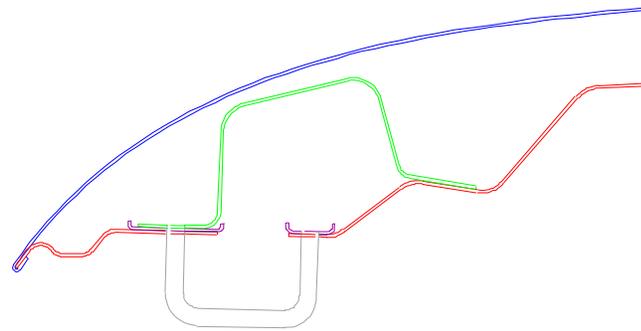


# Benchmarking

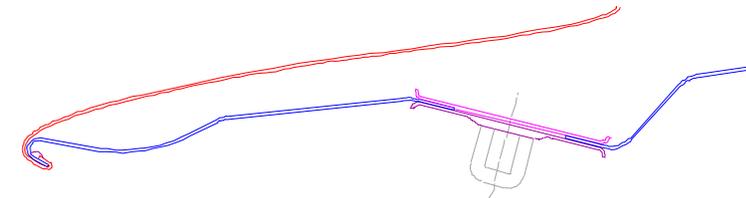
## *Data Gathering - Design Evaluation Typical Sections - Hood - Latch*



Reinforcement doubles inner panel



Reinforcement forms additional section & resists denting load on outer



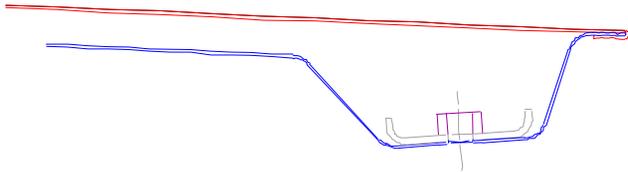
Double sided reinforcement of the inner panel



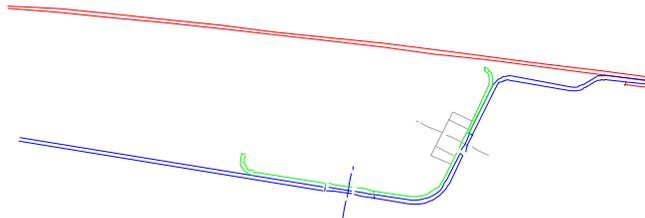


# Benchmarking

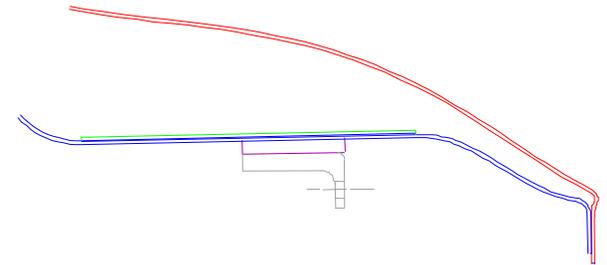
## *Data Gathering - Design Evaluation Typical Sections - Hood - Hinge*



Local reinforcement on flat of inner panel



Local reinforcement on side of section



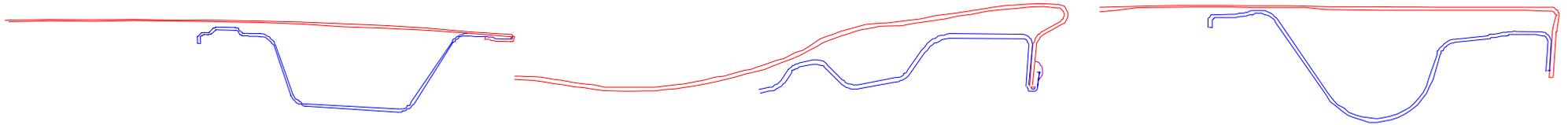
Down-turned flange & MIG welded hinge





## **Benchmarking**

### ***Data Gathering - Design Evaluation Typical Sections - Hood - Side Beam***



Hemmed outer to inner,  
horizontal flange

Hemmed inner to outer,  
vertical flange

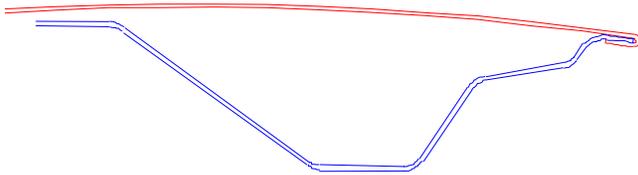
Spot welded outer to  
inner, vertical flange



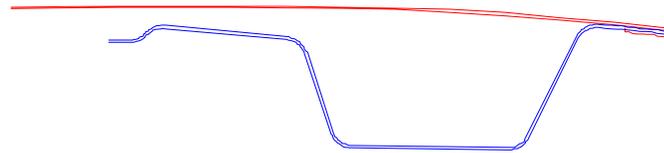


## Benchmarking

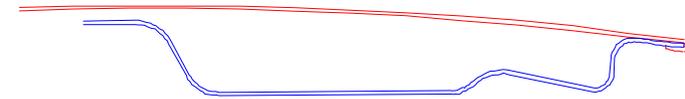
***Data Gathering - Design Evaluation  
Typical Sections - Hood - Rear Beam***



Deep section, hemmed rear edge



More traditional depth & profile



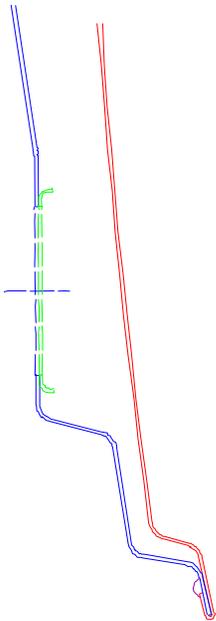
Shallow section, allows additional clearance for plenum



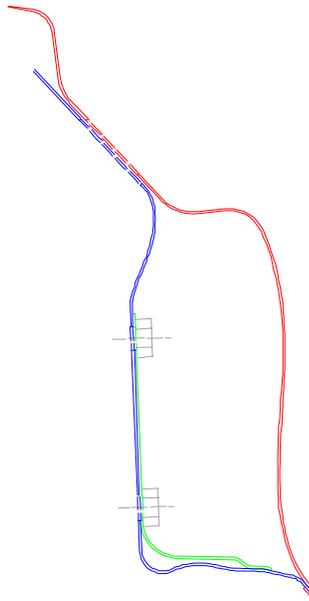


## Benchmarking

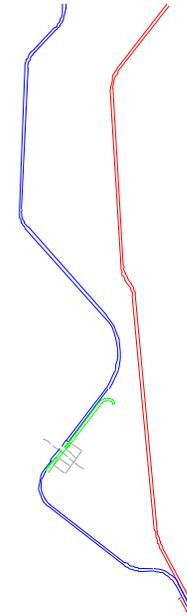
### *Data Gathering - Design Evaluation Typical Sections - Decklid - Latch*



Latch attached to decklid with doubling reinforcement



Lock attached to decklid with doubling reinforcement



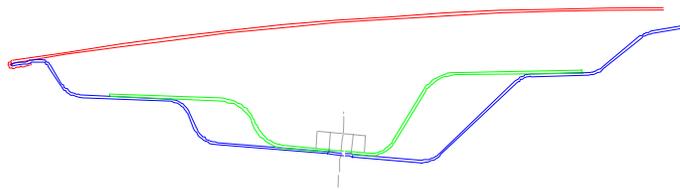
Inner panel reinforced with local reinforcement



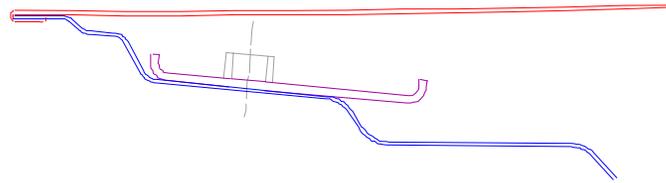


# Benchmarking

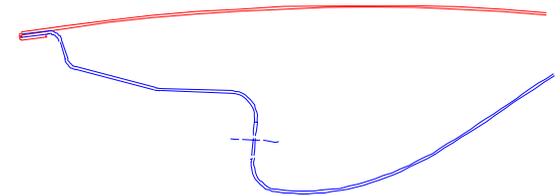
## *Data Gathering - Design Evaluation Typical Sections - Decklid - Hinge*



Reinforcement forms additional section with inner panel



Reinforcement doubles inner panel



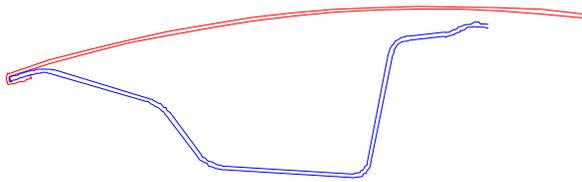
Hinge mounts to side wall of section



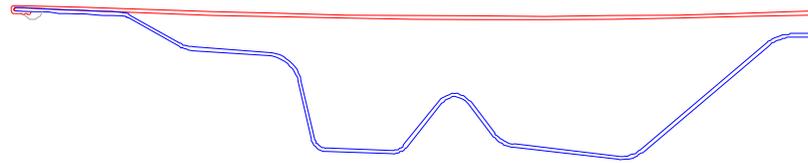


# Benchmarking

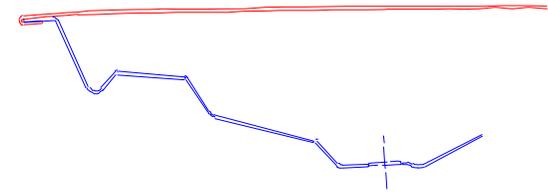
## *Data Gathering - Design Evaluation Typical Sections - Decklid - Side Beam*



Hemmed outer to inner,  
simple light section



Hemmed outer to inner,  
more complicated heavier  
section



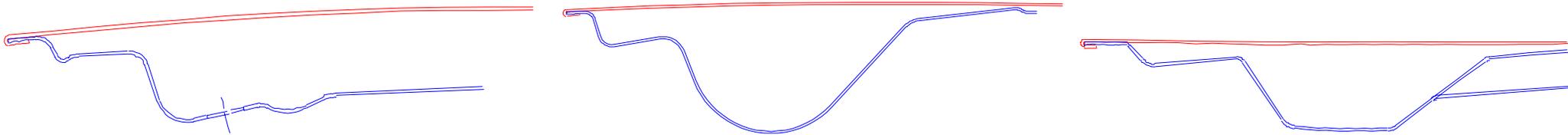
Hemmed outer to inner  
deeper section





## Benchmarking

***Data Gathering - Design Evaluation  
Typical Sections - Decklid - Front Beam***



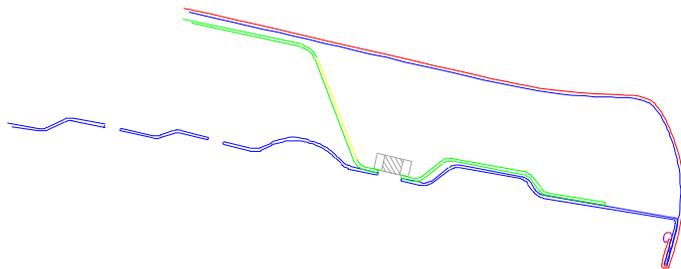
All very similar sections, hemmed outer to inner



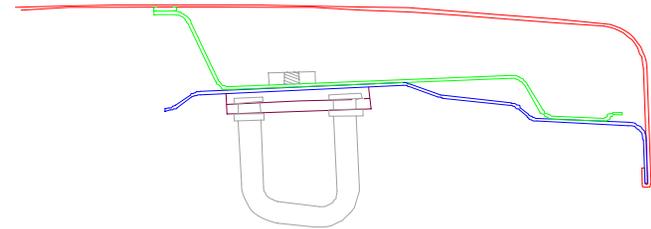


## **Benchmarking**

### ***Data Gathering - Design Evaluation Typical Sections - Hatchback - Latch***



Reinforcement forms  
section with inner panel



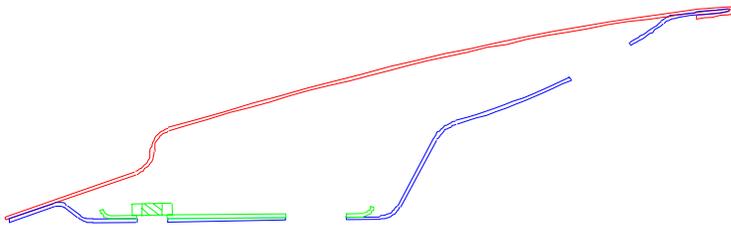
Similar section showing  
attachment of striker



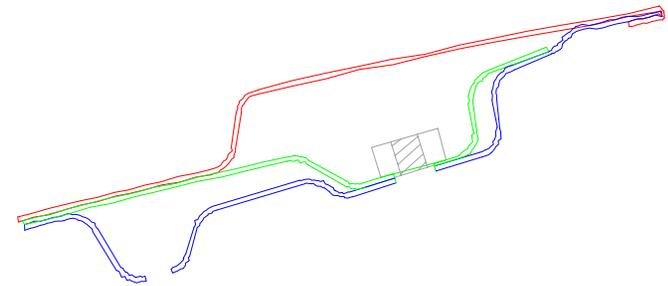


# Benchmarking

## *Data Gathering - Design Evaluation Typical Sections - Hatchback - Hinge*



Reinforcement doubles  
inner panel



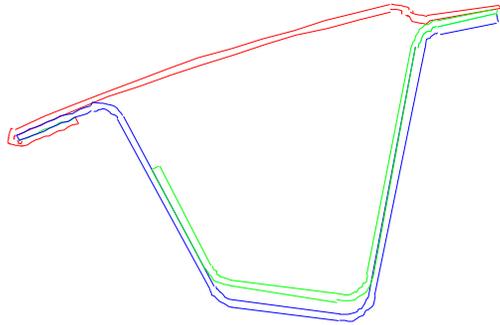
Reinforcement forms  
extra boxing



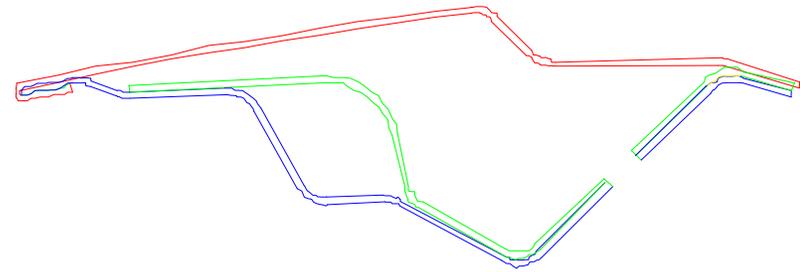


# Benchmarking

## *Data Gathering - Design Evaluation Typical Sections - Hatchback - Side Beam*



Side reinforcement with a doubling piece



Reinforcement forms extra boxing

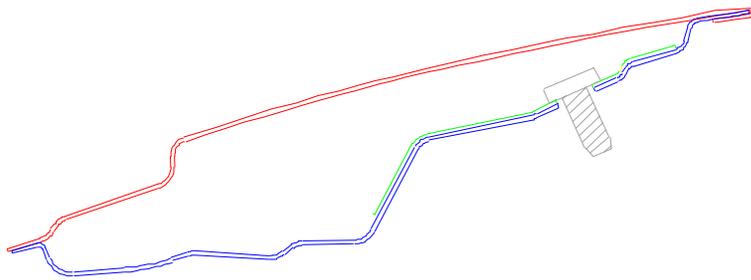




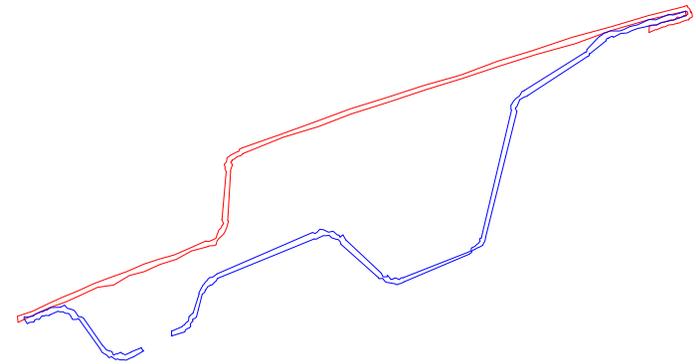
## Benchmarking

**Data Gathering - Design Evaluation**

**Typical Sections - Hatchback - Front Beam**



Spot welded in glass opening  
hemmed at trim edge



Similar but smaller section  
provides a lighter solution





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Audi A6**

| Closure                                            |        | Door                | Hood | Decklid |
|----------------------------------------------------|--------|---------------------|------|---------|
| <b>Weight</b>                                      |        |                     |      |         |
| BIW (Bracket, Reinforcement)                       | kg     | 9.25                |      |         |
| Door frame Module                                  | kg     | 3.45                |      |         |
| Door beam (Aluminum)                               | kg     | 1.225               |      |         |
| Sum BIW and Door frame                             | kg     | 13.93               |      |         |
| Hinge (2X)                                         | kg     | 1.4                 |      |         |
| Latch & Lock                                       | kg     | N/A                 |      |         |
| Doorcheck                                          | kg     | integrated in Hinge |      |         |
| Window regulator / Door Inner Module               | kg     | 1.8                 |      |         |
| Type of Window regulator                           |        | Cable               |      |         |
| Mirror                                             | kg     | N/A                 |      |         |
| Trim / Insulation                                  | kg     | N/A                 |      |         |
| Sealing                                            | kg     | 0.6                 |      |         |
| Wiring Harness                                     | kg     | N/A                 |      |         |
| Weight of Speaker                                  | kg     | N/A                 |      |         |
| Weight Complete                                    | kg     | N/A                 |      |         |
| Q = BIW / Complete                                 |        | N/A                 |      |         |
| Mass / Surface                                     | kg/sqm | 17.85               |      |         |
| <b>Dimensions</b>                                  |        |                     |      |         |
| Length (X)                                         | mm     | 1130                |      |         |
| Height (Z)                                         | mm     | 1140                |      |         |
| Width (Y)                                          | mm     |                     |      |         |
| True Surface Area Calculated                       | sqm    | 0.78                |      |         |
| Depth with / without Trim                          | mm     | 0/133               |      |         |
| Material thickness inner / outer panel             | mm     | 1.76/1.36/0.66      |      |         |
| Material thickness Glass                           | mm     | N/A                 |      |         |
| Curvature Glass                                    |        | N/A                 |      |         |
| Beltline / Bottom                                  | mm     | 1085                |      |         |
| Hinge / Hinge (Hingespread)                        | mm     | 360                 |      |         |
| Length / Hingespread Ratio                         |        | 3.1                 |      |         |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1010/76/290         |      |         |
| Material thickness Hinge                           | mm     | 3.9                 |      |         |
| <b>Specification</b>                               |        |                     |      |         |
| Number of Brackets / Reinforcements                |        | 5                   |      |         |
| Number of Parts total                              |        | 7                   |      |         |
| Number of Weldspots                                |        | 42                  |      |         |
| Area / Thickness of Side Intrusion beam            |        | 464 / 1.8           |      |         |
| Length of Side Intrusion beam                      | mm     | 1025                |      |         |
| Inertia of Side Intrusion beam                     | mm     | 63944               |      |         |
| Attachment Type of Side Intrusion beam             |        | bolted              |      |         |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - BMW 528i**

| Closure                                           |        | Door       | Hood        | Decklid    |
|---------------------------------------------------|--------|------------|-------------|------------|
| <b>Weight</b>                                     |        |            |             |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)        | kg     | 16.4       | 21.3        | 12.05      |
| Glass                                             | kg     |            |             |            |
| Hinge (2X)                                        | kg     |            |             |            |
| Latch & Lock                                      | kg     |            |             |            |
| Doorcheck                                         | kg     |            |             |            |
| Window regulator / Superplug                      | kg     | 2          |             |            |
| Type of Window regulator                          |        | Cable      |             |            |
| Exterior rear Console                             | kg     |            |             |            |
| Mirror                                            | kg     |            |             |            |
| Trim / Insulation                                 | kg     |            |             |            |
| Sealing                                           | kg     |            |             |            |
| Wiring Harness                                    | kg     |            |             |            |
| Weight of Speaker                                 | kg     |            |             |            |
| Sum electric components                           | kg     |            |             |            |
| Weight Complete                                   | kg     |            |             |            |
| Q = BIW / Complete                                |        |            |             |            |
| Mass / Surface                                    | kg/sqm | 19.76      | 13.23       | 16.07      |
| <b>Dimensions</b>                                 |        |            |             |            |
| Length (X)                                        | mm     | 1090       | 1415        | 780        |
| Height (Z)                                        | mm     | 1140       |             |            |
| Width (Y)                                         | mm     |            | 1525        | 1200       |
| True Surface Area Calculated                      | sqm    | 0.83       | 1.61        | 0.75       |
| Depth with / without Trim                         | mm     | 210/130    |             |            |
| Material thickness inner / outer panel            | mm     | 0.83/0.77  | 0.57/1      | 0.7/0.72   |
| Material thickness Glass                          | mm     | 4          |             |            |
| Curvature Glass                                   | mm     | N/A        |             |            |
| Beltline / Bottom                                 | mm     | 665        |             |            |
| Hinge / Hinge (Hingespread)                       | mm     | 295        | 1400        | 1145       |
| Length / Hingespread Ratio                        |        | 3.7        | 1.0         | 0.7        |
| Hinge / Latch (horizontal / vertical / upr / lwr) | mm     | 950/50/245 | 1085/Center | 490/Center |
| Material thickness Hinge                          | mm     | 8          | 4           | 4          |
| <b>Specification</b>                              |        |            |             |            |
| Number of Brackets / Reinforcements               |        | 8          | 6           | 3          |
| Number of Parts total                             |        | 12         | 8           | 5          |
| Number of Weldspots                               |        | 52         | 110         | 27         |
| Area / Thickness of Side Intrusion Beam           |        | 225 / 2.48 |             |            |
| Length of Side Intrusion Beam                     | mm     | 980        |             |            |
| Inertia of Side Intrusion Beam                    | mm     | 75778      |             |            |
| Attachment Type of Side Intrusion Beam            |        | bolted     |             |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Cadillac Sedan Deville**

| Closure                                            |        | Door        | Hood     | Decklid   |
|----------------------------------------------------|--------|-------------|----------|-----------|
| <b>Weight</b>                                      |        |             |          |           |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 17.7        |          |           |
| Glass                                              | kg     |             |          |           |
| Hinge (2X)                                         | kg     |             |          |           |
| Latch & Lock                                       | kg     |             |          |           |
| Doorcheck                                          | kg     |             |          |           |
| Window regulator / Superplug                       | kg     |             |          |           |
| Type of Window regulator                           |        |             |          |           |
| Exterior rear Console                              | kg     |             |          |           |
| Mirror                                             | kg     |             |          |           |
| Trim / Insulation                                  | kg     |             |          |           |
| Sealing                                            | kg     |             |          |           |
| Wiring Harness                                     | kg     |             |          |           |
| Weight of Speaker                                  | kg     |             |          |           |
| Sum electric components                            | kg     |             |          |           |
| Weight Complete                                    | kg     |             |          |           |
| Q = BIW / Complete                                 |        |             |          |           |
| Mass / Surface                                     | kg/sqm | 17.86       |          |           |
| <b>Dimensions</b>                                  |        |             |          |           |
| Length (X)                                         | mm     | 1150        |          |           |
| Height (Z)                                         | mm     | 1240        |          |           |
| Width (Y)                                          | mm     |             |          |           |
| True Surface Area Calculated                       | sqm    | 0.99        |          |           |
| Depth with / without Trim                          | mm     | 170/145     |          |           |
| Material thickness inner / outer panel             | mm     | 0.77/0.77   | 0.61/0.7 | 0.96/0.74 |
| Material thickness Glass                           | mm     |             |          |           |
| Curvature Glass                                    | mm     |             |          |           |
| Beltline / Bottom                                  | mm     | 705         |          |           |
| Hinge / Hinge (Hingespread)                        | mm     | 370         |          |           |
| Length / Hingespread Ratio                         |        | 3.1         |          |           |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 970/180/190 |          |           |
| Material thickness Hinge                           | mm     |             |          |           |
| <b>Specification</b>                               |        |             |          |           |
| Number of Brackets / Reinforcements                |        | 9           |          |           |
| Number of Parts total                              |        | 11          |          |           |
| Number of Weldspots                                |        | 52          |          |           |
| Area / Thickness of Side Intrusion Beam            |        | 233/2.4     |          |           |
| Length of Side Intrusion Beam                      | mm     | 890         |          |           |
| Inertia of Side Intrusion Beam                     | mm     | 24603       |          |           |
| Attachment Type of Side Intrusion Beam             |        | spotwelded  |          |           |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Chevrolet Malibu**

| Closure                                            |        | Door       | Hood       | Decklid    |
|----------------------------------------------------|--------|------------|------------|------------|
| <b>Weight</b>                                      |        |            |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 16.05      | 16.05      | 11         |
| Glass                                              | kg     | 3.38       |            |            |
| Hinge (2X)                                         | kg     | 0.48       | 0.34       | 0.9        |
| Latch & Lock                                       | kg     | 0.995      | Striker    | 0.35       |
| Doorcheck                                          | kg     | 0.255      |            |            |
| Window regulator / Superplug                       | kg     | 3.79       |            |            |
| Type of Window regulator                           |        | crossarm   |            |            |
| Exterior rear Console                              | kg     |            |            |            |
| Mirror                                             | kg     | 0.97       |            |            |
| Trim / Insulation                                  | kg     | 3.03       | 0.52       | no         |
| Sealing                                            | kg     | 2          | on Body    | on Body    |
| Wiring Harness                                     | kg     | 0.61       |            |            |
| Weight of Speaker                                  | kg     | 0.465      |            |            |
| Sum electric components                            | kg     | 1.075      |            |            |
| Weight Complete                                    | kg     | 28.8       | 16.57      | 11.6       |
| Q = BIW / Complete                                 |        | 0.56       | 0.97       | 0.95       |
| Mass / Surface                                     | kg/sqm | 20.58      | 10.70      | 11.83      |
| <b>Dimensions</b>                                  |        |            |            |            |
| Length (X)                                         | mm     | 1075       | 1170       | 810        |
| Height (Z)                                         | mm     | 1165       |            |            |
| Width (Y)                                          | mm     |            | 1370       | 1250       |
| True Surface Area Calculated                       | sqm    | 0.78       | 1.50       | 0.93       |
| Depth with / without Trim                          | mm     | 120/225    |            |            |
| Material thickness inner / outer panel             | mm     | 0.7/0.7    | 0.61/0.66  | 0.61/0.66  |
| Material thickness Glass                           | mm     | 4          |            |            |
| Curvature Glass                                    | mm     | 28         |            |            |
| Beltline / Bottom                                  | mm     | 680        |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 355        | 1235       | 1035       |
| Length / Hingespread Ratio                         |        | 3.0        | 0.9        | 0.8        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 995/85/170 | 940/Center | 450/Center |
| Material thickness Hinge                           | mm     | 6.5        | 3          | 20x20x1.8  |
| <b>Specification</b>                               |        |            |            |            |
| Number of Brackets / Reinforcements                |        | 7          | 5          | 1          |
| Number of Parts total                              |        | 12         | 7          | 3          |
| Number of Weldspots                                |        | 80         | 8          | 2          |
| Area / Thickness of Side Intrusion Beam            |        | 236/2      |            |            |
| Length of Side Intrusion Beam                      | mm     | 980        |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 31146      |            |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Dodge Stratus**

| Closure                                            |        | Door         | Hood       | Hatch      |
|----------------------------------------------------|--------|--------------|------------|------------|
| <b>Weight</b>                                      |        |              |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 16.8         | 15.35      | 11.65      |
| Glass                                              | kg     | 3.58         |            |            |
| Hinge (2X)                                         | kg     | 0.76         | 0.31       | 1.95       |
| Latch & Lock                                       | kg     | 0.76         | Striker    | 0.5        |
| Doorcheck                                          | kg     | 0.365        |            |            |
| Window regulator / Superplug                       | kg     | 2.805        |            |            |
| Type of Window regulator                           |        | cross arm    |            |            |
| Exterior rear Console                              | kg     |              |            | 0.155      |
| Mirror                                             | kg     | 0.96         |            |            |
| Trim / Insulation                                  | kg     | 3.08         | 0.35       | 0.04       |
| Sealing                                            | kg     | 2.15         | 0.3        | 0.025      |
| Wiring Harness                                     | kg     | 0.755        |            |            |
| Weight of Speaker                                  | kg     | 0.925        |            |            |
| Sum electric components                            | kg     | 1.68         |            |            |
| Weight Complete                                    | kg     | 32.17        | 15.95      | 12.4       |
| Q = BIW / Complete                                 |        | 0.52         | 0.96       | 0.94       |
| Mass / Surface                                     | kg/sqm | 20.00        | 13.23      | 12.01      |
| <b>Dimensions</b>                                  |        |              |            |            |
| Length (X)                                         | mm     | 1150         | 890        | 870        |
| Height (Z)                                         | mm     | 1145         |            |            |
| Width (Y)                                          | mm     |              | 1450       | 1085       |
| True Surface Area Calculated                       | sqm    | 0.84         | 1.16       | 0.97       |
| Surface Area projected                             | sqm    | 0.83         | 1.29       | 0.95       |
| Depth with / without Trim                          | mm     | 210/135      |            |            |
| Material thickness inner / outer panel             | mm     | 0.61/0.79    | 0.57/0.79  | 0.51/0.72  |
| Material thickness Glass                           | mm     | 4            |            |            |
| Curvature Glass                                    | mm     | N/A          |            |            |
| Beltline / Bottom                                  | mm     | 635          |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 320          | 1385       | 1020       |
| Length / Hingespread Ratio                         |        | 3.6          | 0.6        | 0.9        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1030/130/190 | 910/Center | 445/Center |
| Material thickness Hinge                           |        | 5            | 2.5        | 2.5        |
| <b>Specification</b>                               |        |              |            |            |
| Number of Brackets / Reinforcements                |        | 7            | 3          | 4          |
| Number of Parts total                              |        | 12           | 5          | 6          |
| Number of Weldspots                                |        | 51           | 24         | 23         |
| Area / Thickness of Side intrusion beam            |        | 246/1.65     |            |            |
| Length of Side Intrusion Beam                      | mm     | 1005         |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 133859       |            |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded   |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Ford Contour**

| Closure                                            |        | Door         | Hood       | Decklid    |
|----------------------------------------------------|--------|--------------|------------|------------|
| <b>Weight</b>                                      |        |              |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 15.844       | 15.05      | 9.93       |
| Glass                                              | kg     | 3.38         |            |            |
| Hinge (2X)                                         | kg     | 0.66         | 0.48       | 1640       |
| Latch & Lock                                       | kg     | 1.185        | Striker    | Striker    |
| Doorcheck                                          | kg     | 0.22         |            |            |
| Window regulator / Superplug                       | kg     | 1.855        |            |            |
| Type of Window regulator                           |        | single cable |            |            |
| Exterior rear Console                              | kg     |              |            | 2.11       |
| Mirror                                             | kg     | 1.24         |            |            |
| Trim / Insulation                                  | kg     | 3.115        |            | 0.22       |
| Sealing                                            | kg     | 1.15         | 0.125      | 0.02       |
| Wiring Harness                                     | kg     | 0.95         |            |            |
| Weight of Speaker                                  | kg     | 0.58         |            |            |
| Sum electric components                            | kg     | 1.53         |            |            |
| Weight Complete                                    | kg     | 29.35        | 15.175     | 12.585     |
| Q = BIW / Complete                                 |        | 0.54         | 0.99       | 0.79       |
| Mass / Surface                                     | kg/sqm | 19.09        | 14.07      | 8.87       |
| <b>Dimensions</b>                                  |        |              |            |            |
| Length (X)                                         | mm     | 1115         | 955        | 722        |
| Height (Z)                                         | mm     | 1170         |            |            |
| Width (Y)                                          | mm     |              | 1425       | 1362       |
| True Surface Area Calculated                       | sqm    | 0.83         | 1.07       | 1.12       |
| Depth with / without Trim                          | mm     | 150/240      |            |            |
| Material thickness inner / outer panel             | mm     | 0.68/0.7     | 0.59/0.63  | 0.59/0.63  |
| Material thickness Glass                           | mm     | 3.25         |            |            |
| Curvature Glass                                    | mm     | 26           |            |            |
| Beltline / Bottom                                  | mm     | 585          |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 315          | 1400       | 1210       |
| Length / Hingespread Ratio                         |        | 3.5          | 0.7        | 0.6        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1015/170/145 | 880/Center | 445/Center |
| Material thickness Hinge                           | mm     | 4.5          | 4          | 20x20x2    |
| <b>Specification</b>                               |        |              |            |            |
| Number of Brackets / Reinforcements                |        | 6            | 3          | 3          |
| Number of Parts total                              |        | 8            | 5          | 5          |
| Number of Weldspots                                |        | 106          | 12         | 7          |
| Area / Thickness of Side Intrusion Beam            |        | 264 / 1.8    |            |            |
| Length of Side Intrusion Beam                      | mm     | 840          |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 37685        |            |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded   |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Ford Probe**

| Closure                                            |        | Door | Hood | Hatch       |
|----------------------------------------------------|--------|------|------|-------------|
| <b>Weight</b>                                      |        |      |      |             |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     |      |      | 12.4        |
| Glass                                              | kg     |      |      | 11.8        |
| Hinge (2X)                                         | kg     |      |      | 0.34        |
| Latch & Lock                                       | kg     |      |      | 0.07        |
| Doorcheck                                          | kg     |      |      |             |
| Window regulator / Superplug                       | kg     |      |      |             |
| Type of Window regulator                           |        |      |      |             |
| Exterior rear Console                              | kg     |      |      | 0.155       |
| Mirror                                             | kg     |      |      |             |
| Trim / Insulation                                  | kg     |      |      | 1.6         |
| Sealing                                            | kg     |      |      | 0.25        |
| Wiring Harness                                     | kg     |      |      | 0           |
| Weight of Speaker                                  | kg     |      |      |             |
| Sum electric components                            | kg     |      |      | 0           |
| Weight Complete                                    | kg     |      |      | 12.4        |
| Q = BIW / Complete                                 |        |      |      | 1.00        |
| Mass / Surface                                     | kg/sqm |      |      | 14.76       |
| <b>Dimensions</b>                                  |        |      |      |             |
| Length (X)                                         | mm     |      |      | 1370        |
| Height (Z)                                         | mm     |      |      |             |
| Width (Y)                                          | mm     |      |      | 1260        |
| True Surface Area Calculated                       | sqm    |      |      | 0.84        |
| Depth with / without Trim                          | mm     |      |      |             |
| Material thickness inner / outer panel             | mm     |      |      | 0.65/1      |
| Material thickness Glass                           | mm     |      |      |             |
| Curvature Glass                                    | mm     |      |      |             |
| Beltline / Bottom                                  | mm     |      |      |             |
| Hinge / Hinge (Hingespread)                        | mm     |      |      | 610         |
| Length / Hingespread Ratio                         |        |      |      | 2.2         |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     |      |      | 1250/Center |
| Material thickness Hinge                           | mm     |      |      | 2           |
| <b>Specification</b>                               |        |      |      |             |
| Number of Brackets / Reinforcements                |        |      |      | 4           |
| Number of Parts total                              |        |      |      | 6           |
| Number of Weldspots                                |        |      |      | 90          |
| Area / Thickness of Side Intrusion Beam            |        |      |      |             |
| Length of Side Intrusion Beam                      | mm     |      |      |             |
| Inertia of Side Intrusion Beam                     | mm     |      |      |             |
| Attachment Type of Side Intrusion Beam             |        |      |      |             |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Ford Taurus**

| Closure                                            |        | Door        | Hood       | Decklid    |
|----------------------------------------------------|--------|-------------|------------|------------|
| <b>Weight</b>                                      |        |             |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 18.72       | 21.66      | 5.9        |
| Glass                                              | kg     | 3.77        |            |            |
| Hinge (2X)                                         | kg     | 1.2         | 0.7        | 0.42       |
| Latch & Lock                                       | kg     | 1.22        | 0.55       | 0.695      |
| Doorcheck                                          | kg     | 0.245       |            |            |
| Window regulator / Superplug                       | kg     | 2.365       |            |            |
| Type of Window regulator                           |        | crossarm    |            |            |
| Exterior rear Console                              | kg     |             |            | 1.9        |
| Mirror                                             | kg     | 0.79        |            |            |
| Trim / Insulation                                  | kg     | 3.7         | 0.85       | 0.565      |
| Sealing                                            | kg     | 2.825       | 0.22       | on Body    |
| Wiring Harness                                     | kg     | 1.195       |            | 0.13       |
| Weight of Speaker                                  | kg     | 0.765       |            |            |
| Sum electric components                            | kg     | 1.96        |            | 0.13       |
| Weight Complete                                    | kg     | 35.97       | 23.965     | 9.06       |
| Q = BIW / Complete                                 |        | 0.52        | 0.90       | 0.65       |
| Mass / Surface                                     | kg/sqm | 20.82       | 13.37      | 5.78       |
| <b>Dimensions</b>                                  |        |             |            |            |
| Length (X)                                         | mm     | 1095        | 900        | 810        |
| Height (Z)                                         | mm     | 1245        |            |            |
| Width (Y)                                          | mm     |             | 1550       | 1335       |
| True Surface Area Calculated                       | sqm    | 0.90        | 1.62       | 1.02       |
| Depth with / without Trim                          | mm     | 340/390     |            |            |
| Material thickness inner / outer panel             | mm     | 0.68 / 0.70 | 0.6 / 0.7  | 0.8/0.8    |
| Material thickness Glass                           | mm     | 3.95        |            |            |
| Curvature Glass                                    | mm     | N/A         |            |            |
| Beltline / Bottom                                  | mm     | 735         |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 340         | 1380       | 1070       |
| Length / Hingespread Ratio                         |        | 3.2         | 0.7        | 0.8        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 950/150/190 | 630/Center | 660/Center |
| Material thickness Hinge                           | mm     | 4           | 2.53       | 2.22       |
| <b>Specification</b>                               |        |             |            |            |
| Number of Brackets / Reinforcements                |        | 10          | 3          | 3          |
| Number of Parts total                              |        | 12          | 5          | 5          |
| Number of Weldspots                                |        | 122         | 128        | 40         |
| Area / Thickness of Side Intrusion Beam            |        | 261 / 1.78  |            |            |
| Length of Side Intrusion Beam                      | mm     | 890         |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 70407       |            |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded  |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Honda Accord**

| Closure                                            |        | Door         | Hood        | Decklid    |
|----------------------------------------------------|--------|--------------|-------------|------------|
| <b>Weight</b>                                      |        |              |             |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 15.9         | 16.78       | 10.04      |
| Glass                                              | kg     | 3.055        |             |            |
| Hinge (2X)                                         | kg     | 0.76         | 0.7         | 0.42       |
| Latch & Lock                                       | kg     | 1.345        | Striker     | 0.78       |
| Doorcheck                                          | kg     | 1.75         |             |            |
| Window regulator / Superplug                       | kg     | 1.285        |             |            |
| Type of Window regulator                           |        | Crossarm     |             |            |
| Exterior rear Console                              | kg     |              |             | 2.15       |
| Mirror                                             | kg     | 1.085        |             |            |
| Trim / Insulation                                  | kg     | 3.12         | no          | on Body    |
| Sealing                                            | kg     | 0.945        | 0.22        | on Body    |
| Wiring Harness                                     | kg     | 0.5          |             | 0.13       |
| Weight of Speaker                                  | kg     | 0.555        |             |            |
| Sum electric components                            | kg     | 1.055        |             | 0.13       |
| Weight Complete                                    | kg     | 29           | 19.3        | 13.45      |
| Q = BIW / Complete                                 |        | 0.55         | 16.90       | 0.75       |
| Mass / Surface                                     | kg/sqm | 23.38        | 10.36       | 10.57      |
| <b>Dimensions</b>                                  |        |              |             |            |
| Length (X)                                         | mm     | 1115         | 1115        | 740        |
| Height (Z)                                         | mm     | 1130         |             |            |
| Width (Y)                                          | mm     |              | 1460        | 1170       |
| True Surface Area Calculated                       | sqm    | 0.68         | 1.62        | 0.95       |
| Depth with / without Trim                          | mm     | 130/         |             |            |
| Material thickness inner / outer panel             | mm     | 0.6 / 0.72   | 0.55 / .72  | 0.66/0.66  |
| Material thickness Glass                           | mm     | 3.5          |             |            |
| Curvature Glass                                    | mm     | 21           |             |            |
| Beltline / Bottom                                  | mm     | 0            |             |            |
| Hinge / Hinge (Hingespread)                        | mm     | 330          | 1380        | 1040       |
| Length / Hingespread Ratio                         |        | 3.4          | 0.8         | 0.7        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1030/120/210 | 1060/Center | 380/Center |
| Material thickness Hinge                           | mm     | 6            | 2.53        | 2.22       |
| <b>Specification</b>                               |        |              |             |            |
| Number of Brackets / Reinforcements                |        | 8            | 3           | 1          |
| Number of Parts total                              |        | 12           | 5           | 3          |
| Number of Weldspots                                |        | 52           | 24          | 14         |
| Area / Thickness of Side Intrusion Beam            |        | 226 / 2.48   |             |            |
| Length of Side Intrusion Beam                      | mm     | 850          |             |            |
| Inertia of Side Intrusion Beam                     | mm     | 23975        |             |            |
| Attachment Type of Side Intrusion Beam             |        | gaswelded    |             |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Mercedes E320**

| Closure                                            |        | Door       | Hood        | Decklid  |
|----------------------------------------------------|--------|------------|-------------|----------|
| <b>Weight</b>                                      |        |            |             |          |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 13.439     | 19.86       | 11.683   |
| Glass                                              | kg     | 3.362      |             |          |
| Hinge (2X)                                         | kg     | 1.494      | 1.558       | 1.482    |
| Latch & Lock                                       | kg     | 1.149      | 0.235       | 0.542    |
| Doorcheck                                          | kg     | 0.501      |             |          |
| Window regulator / Superplug                       | kg     | 1.45       |             |          |
| Type of Window regulator                           |        | crossarm   |             |          |
| Exterior rear Console                              | kg     |            |             |          |
| Mirror                                             | kg     | N/A        |             |          |
| Trim / Insulation                                  | kg     | 2.604      | 2.09        | 1.034    |
| Sealing                                            | kg     | 1.574      | 0.586       | 1.09     |
| Wiring Harness                                     | kg     | N/A        |             |          |
| Weight of Speaker                                  | kg     | N/A        |             |          |
| Sum electric components                            | kg     | N/A        |             |          |
| Weight Complete                                    | kg     | 27.889     | 26.635      | 18.319   |
| Q = BIW / Complete                                 |        | 0.48       | 0.75        | 0.64     |
| Mass / Surface                                     | kg/sqm | 17.01      | 14.19       | 10.07    |
| <b>Dimensions</b>                                  |        |            |             |          |
| Length (X)                                         | mm     | 950        | 1375        | 850      |
| Height (Z)                                         | mm     | 1130       |             |          |
| Width (Y)                                          | mm     |            | 1440        | 1265     |
| True Surface Area Calculated                       | sqm    | 0.79       | 1.40        | 1.16     |
| Depth with / without Trim                          | mm     | 135/210    |             |          |
| Material thickness inner / outer panel             | mm     | 0.74/0.74  | 0.7/0.8     | 0.7/0.72 |
| Material thickness Glass                           | mm     | 4          |             |          |
| Curvature Glass                                    | mm     | N/A        |             |          |
| Beltline / Bottom                                  | mm     | 645        |             |          |
| Hinge / Hinge (Hingespread)                        | mm     | 350        | 1430        | 1130     |
| Length / Hingespread Ratio                         |        | 2.7        | 1.0         | 0.8      |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 930/60/290 | 770/252/252 | 1.8      |
| Material thickness Hinge                           | mm     | 5.5        | 2.5         | 1.87     |
| <b>Specification</b>                               |        |            |             |          |
| Number of Brackets / Reinforcements                |        | 7          | 3           | 5        |
| Number of Parts total                              |        | 14         | 5           | 7        |
| Number of Weldspots                                |        | 88         | 34          | 12       |
| Area / Thickness of Side Intrusion Beam            |        | 460/2.75   |             |          |
| Length of Side Intrusion Beam                      | mm     | 820        |             |          |
| Inertia of Side Intrusion Beam                     | mm     | 163500     |             |          |
| Attachment Type of Side Intrusion Beam             |        | spotwelded |             |          |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Mitsubishi Eclipse**

| Closure                                            |        | Door   | Hood | Decklid     |
|----------------------------------------------------|--------|--------|------|-------------|
| <b>Weight</b>                                      |        |        |      |             |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     |        |      | 12.6        |
| Glass                                              | kg     |        |      | 11.8        |
| Hinge (2X)                                         | kg     |        |      | N/A         |
| Latch & Lock                                       | kg     |        |      | 0.105       |
| Doorcheck                                          | kg     |        |      | 1.15        |
| Window regulator / Superplug                       | kg     |        |      |             |
| Type of Window regulator                           |        |        |      |             |
| Exterior rear Console                              | kg     |        |      | 1.15        |
| Mirror                                             | kg     |        |      |             |
| Trim / Insulation                                  | kg     |        |      | 1.6         |
| Sealing                                            | kg     |        |      | on Body     |
| Wiring Harness                                     | kg     |        |      | on Body     |
| Weight of Speaker                                  | kg     |        |      |             |
| Sum electric components                            | kg     |        |      | 0           |
| Weight Complete                                    | kg     |        |      | 24.4        |
| Q = BIW / Complete                                 |        |        |      | 0.52        |
| Mass / Surface                                     | kg/sqm | kg/sqm |      | 15.24       |
| <b>Dimensions</b>                                  |        |        |      |             |
| Length (X)                                         | mm     |        |      | 1460        |
| Height (Z)                                         | mm     |        |      |             |
| Width (Y)                                          | mm     |        |      | 1245        |
| True Surface Area Calculated                       | sqm    |        |      | 0.83        |
| Depth with / without Trim                          | mm     |        |      |             |
| Material thickness inner / outer panel             | mm     |        |      | 0.63/0.681  |
| Material thickness Glass                           | mm     |        |      |             |
| Curvature Glass                                    | mm     |        |      |             |
| Beltline / Bottom                                  | mm     |        |      |             |
| Hinge / Hinge (Hingespread)                        | mm     |        |      | 700         |
| Length / Hingespread Ratio                         |        |        |      | 2.1         |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     |        |      | 1280/Center |
| Material thickness Hinge                           | mm     |        |      | 3.2         |
| <b>Specification</b>                               |        |        |      |             |
| Number of Brackets / Reinforcements                |        |        |      | 7           |
| Number of Parts total                              |        |        |      | 9           |
| Number of Weldspots                                |        |        |      | 90          |
| Area / Thickness of Side Intrusion Beam            |        |        |      |             |
| Length of Side Intrusion Beam                      | mm     |        |      |             |
| Inertia of Side Intrusion Beam                     | mm     |        |      |             |
| Attachment Type of Side Intrusion Beam             |        |        |      |             |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Nissan Sentra**

| Closure                                            |        | Door         | Hood       | Decklid    |
|----------------------------------------------------|--------|--------------|------------|------------|
| <b>Weight</b>                                      |        |              |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 15.2         | 14.05      | 9.95       |
| Glass                                              | kg     | 2.835        |            |            |
| Hinge (2X)                                         | kg     | 0.76         | 0.54       | 0.23       |
| Latch & Lock                                       | kg     | 0.945        | Striker    | 2.044      |
| Doorcheck                                          | kg     | 0.155        |            |            |
| Window regulator / Superplug                       | kg     | 1.195        |            |            |
| Type of Window regulator                           |        | cross arm    |            |            |
| Exterior rear Console                              | kg     |              |            | 1.395      |
| Mirror                                             | kg     | 0.86         |            |            |
| Trim / Insulation                                  | kg     | 3.66         | no         | no         |
| Sealing                                            | kg     | 0.95         | 0.24       | no         |
| Wiring Harness                                     | kg     | 0.545        |            |            |
| Weight of Speaker                                  | kg     | 0.44         |            |            |
| Sum electric components                            | kg     | 0.985        |            |            |
| Weight Complete                                    | kg     | 27.95        | 14.3       | 11.8       |
| Q = BIW / Complete                                 |        | 0.54         | 0.98       | 0.84       |
| Mass / Surface                                     | kg/sqm | 18.10        | 9.89       | 9.95       |
| <b>Dimensions</b>                                  |        |              |            |            |
| Length (X)                                         | mm     | 1100         | 975        | 795        |
| Height (Z)                                         | mm     | 1145         |            |            |
| Width (Y)                                          | mm     |              | 1405       | 1170       |
| True Surface Area Calculated                       | sqm    | 0.84         | 1.42       | 1.00       |
| Depth with / without Trim                          | mm     | 135/235      |            |            |
| Material thickness inner / outer panel             | mm     | 0.59 / .66   | 0.5 / 0.68 | 0.57/0.71  |
| Material thickness Glass                           | mm     | 3.5          |            |            |
| Curvature Glass                                    | mm     | 25           |            |            |
| Beltline / Bottom                                  | mm     | 625          |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 320          | 1280       | 1060       |
| Length / Hingespread Ratio                         |        | 3.4          | 0.8        | 0.8        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 980/150/170  | 870/Center | 410/Center |
| Material thickness Hinge                           | mm     | 4.3          | 3.15       | 24x24x1.98 |
| <b>Specification</b>                               |        |              |            |            |
| Number of Brackets / Reinforcements                |        | 12           | 3          | 5          |
| Number of Parts total                              |        | 14           | 5          | 7          |
| Number of Weldspots                                |        | 90           | 20         | 29         |
| Area / Thickness of Side Intrusion Beam            |        | 232.5 / 2.26 |            |            |
| Length of Side Intrusion Beam                      | mm     | 840          |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 31295        |            |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded   |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Porsche Boxster**

| Closure                                            |        | Door         | Hood  | Decklid |
|----------------------------------------------------|--------|--------------|-------|---------|
| <b>Weight</b>                                      |        |              |       |         |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 15.17        |       |         |
| Glass                                              | kg     | 3.49         |       |         |
| Hinge (2X)                                         | kg     | 1            |       |         |
| Latch & Lock                                       | kg     | 0.98         |       |         |
| Doorcheck                                          | kg     | 0.405        |       |         |
| Window regulator / Superplug                       | kg     | 1.8          |       |         |
| Type of Window regulator                           |        | cable        |       |         |
| Exterior rear Console                              | kg     |              |       |         |
| Mirror                                             | kg     | N/A          |       |         |
| Trim / Insulation                                  | kg     | 3.23         |       |         |
| Sealing                                            | kg     | 0.97         |       |         |
| Wiring Harness                                     | kg     | 0.64         |       |         |
| Weight of Speaker                                  | kg     | N/A          |       |         |
| Sum electric components                            | kg     | N/A          |       |         |
| Weight Complete                                    | kg     | 29.5         |       |         |
| Q = BIW / Complete                                 |        | 0.51         |       |         |
| Mass / Surface                                     | kg/sqm | kg/sqm       | 19.96 |         |
| <b>Dimensions</b>                                  |        |              |       |         |
| Length (X)                                         | mm     | 1264         |       |         |
| Height (Z)                                         | mm     | 622          |       |         |
| Width (Y)                                          | mm     |              |       |         |
| True Surface Area Calculated                       | sqm    | 0.76         |       |         |
| Depth with / without Trim                          | mm     | 146/         |       |         |
| Material thickness inner / outer panel             | mm     | 0.8/0.9      |       |         |
| Material thickness Glass                           | mm     | N/A          |       |         |
| Curvature Glass                                    | mm     | N/A          |       |         |
| Beltline / Bottom                                  | mm     | 622          |       |         |
| Hinge / Hinge (Hingespread)                        | mm     | 300          |       |         |
| Length / Hingespread Ratio                         |        | 4.2          |       |         |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1080/105/195 |       |         |
| Material thickness Hinge                           | mm     | die cast     |       |         |
| <b>Specification</b>                               |        |              |       |         |
| Number of Brackets / Reinforcements                |        | 7            |       |         |
| Number of Parts total                              |        | 9            |       |         |
| Number of Weldspots                                |        | 0            |       |         |
| Area / Thickness of Side Intrusion Beam            |        | 268/1.7      |       |         |
| Length of Side Intrusion Beam                      | mm     | 890          |       |         |
| Inertia of Side Intrusion Beam                     | mm     | 29566        |       |         |
| Attachment Type of Side Intrusion Beam             |        | bolted       |       |         |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Renault Laguna**

| Closure                                         |        | Door      | Hood    | Hatch  |
|-------------------------------------------------|--------|-----------|---------|--------|
| <b>Weight</b>                                   |        |           |         |        |
| BIW (Bracket, Reinf.)                           | kg     | 14.911    | 17.803  | 13.372 |
| Side Intrusion Beam                             | kg     | 2.315     |         |        |
| Door Inner Module                               | kg     | 0.88      |         |        |
| BIW Total                                       |        | 18.106    | 17.803  | 13.372 |
| Glass                                           | kg     | 2.993     |         | 11.079 |
| Hinge (2X)                                      | kg     | 1.034     | 1.818   | 1.437  |
| Latch & Lock                                    | kg     | 0.821     | Striker | 0.881  |
| Doorcheck / Gasstruts                           | kg     | 0.231     |         | 1.042  |
| Window regulator                                | kg     | 1.801     |         |        |
| Type of Window regulator                        |        | cross arm |         |        |
| Exterior rear Console                           |        |           |         |        |
| Mirror                                          | kg     | 1.502     |         |        |
| Trim / Insulation                               | kg     | 2.462     |         | 1.651  |
| Sealing                                         | kg     | 2.997     | 0.587   | 1.548  |
| Wiring Harness                                  | kg     | 0.442     |         | 0.842  |
| Number / Weight of Speaker                      | kg     | N/A       |         |        |
| Sum electric. components                        | kg     | 0.442     |         |        |
| Weight Complete                                 | kg     | 32.831    | 20.208  | 31.852 |
| Q = BIW / Complete                              |        | 0.55      | 0.88    | 0.42   |
| Mass / Surface                                  | kg/sqm | 20.12     | 10.19   | 13.14  |
| <b>Dimensions</b>                               |        |           |         |        |
| Length (X)                                      | mm     | 1100      | 0       | 0      |
| Height (Z)                                      | mm     | 1110      |         |        |
| Width (Y)                                       | mm     |           | 0       | 0      |
| True Surface Area Calculated                    | sqm    | 0.74      | 1.75    | 1.02   |
| Depth with / without Trim                       | mm     | 180/145   |         |        |
| Material thickness inner / outer panel          | mm     | N/A       | N/A     | N/A    |
| Material thickness Glass                        | mm     | N/A       |         |        |
| Curvature Glass                                 |        | N/A       |         |        |
| Beltline / Bottom                               | mm     | 0         |         |        |
| Hinge / Hinge (Hingespread)                     | mm     | 310       | 0       | 0      |
| Length / Hingespread Ratio                      |        | 3.5       | N/A     | N/A    |
| Hinge / Latch (horizontal / vertical /Upr / lwr | mm     | N/A       | N/A     | N/A    |
| Material thickness Hinge                        |        | N/A       | N/A     | N/A    |
| <b>Specification</b>                            |        |           |         |        |
| Number of Brackets / Reinforcements             |        | N/A       | N/A     | N/A    |
| Number of Parts total                           |        | N/A       | N/A     | N/A    |
| Number of Weldspots                             |        | N/A       | N/A     | N/A    |
| Area / Thickness of Side Intrusion beam         |        | N/A       |         |        |
| Length of Side Intrusion beam                   | mm     | N/A       |         |        |
| Inertia of Side Intrusion beam                  | mm     | N/A       |         |        |
| Attachment Type of Side Intrusion beam          |        | N/A       |         |        |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Saturn LS**

| Closure                                            |        | Door        | Hood       | Decklid    |
|----------------------------------------------------|--------|-------------|------------|------------|
| <b>Weight</b>                                      |        |             |            |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 14.18       | 12.3       | 9.61       |
| Glass                                              | kg     | 2.84        |            |            |
| Hinge (2X)                                         | kg     | 0.7         | 0.7        | 0.42       |
| Latch & Lock                                       | kg     | 1.075       | Striker    | 0.5        |
| Doorcheck                                          | kg     | N/A         |            |            |
| Window regulator / Superplug                       | kg     | 2.845       |            |            |
| Type of Window regulator                           |        | cross arm   |            |            |
| Exterior rear Console                              | kg     |             |            | 2.15       |
| Mirror                                             | kg     | 0.745       |            |            |
| Trim / Insulation                                  | kg     | 2.455       | 0.45       | no         |
| Sealing                                            | kg     | 1.45        | no         | no         |
| Wiring Harness                                     | kg     | 1.95        |            | 0.13       |
| Weight of Speaker                                  | kg     | 0.45        |            |            |
| Sum electric components                            | kg     | 2.4         |            | 0.13       |
| Weight Complete                                    | kg     | 27.55       | 19.3       | 13.45      |
| Q = BIW / Complete                                 |        | 0.51        | 0.64       | 0.71       |
| Mass / Surface                                     | kg/sqm | 20.85       | 8.79       | 10.92      |
| <b>Dimensions</b>                                  |        |             |            |            |
| Length (X)                                         | mm     | 975.00      | 990.00     | 740.00     |
| Height (Z)                                         | mm     | 1110        |            |            |
| Width (Y)                                          | mm     |             | 1370       | 1170       |
| True Surface Area Calculated                       | sqm    | 0.68        | 1.4        | 0.88       |
| Depth with / without Trim                          | mm     | 140/115     |            |            |
| Material thickness inner / outer panel             | mm     | 0.72        | 0.55 / .59 | 0.66/0.66  |
| Material thickness Glass                           | mm     | 3.50        |            |            |
| Curvature Glass                                    | mm     | 34          |            |            |
| Beltline / Bottom                                  | mm     | 610         |            |            |
| Hinge / Hinge (Hingespread)                        | mm     | 360         | 1270       | 1040       |
| Length / Hingespread Ratio                         |        | 2.7         | 0.8        | 0.7        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 960/140/220 | 820/Center | 380/Center |
| Material thickness Hinge                           | mm     | 8           | 2.6        | 2.22       |
| <b>Specification</b>                               |        |             |            |            |
| Number of Brackets / Reinforcements                |        | 10.0        | 3.0        | 1.0        |
| Number of Parts total                              |        | 22          | 5          | 3          |
| Number of Weldspots                                |        | 140         | 16         | 14         |
| Area / Thickness of Side Intrusion Beam            |        | 226 / 2.48  |            |            |
| Length of Side Intrusion Beam                      | mm     | 870         |            |            |
| Inertia of Side Intrusion Beam                     | mm     | 23975       |            |            |
| Attachment Type of Side Intrusion Beam             |        | gaswelded   |            |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - Toyota Camry**

| Closure                                            |        | Door       | Hood        | Decklid    |
|----------------------------------------------------|--------|------------|-------------|------------|
| <b>Weight</b>                                      |        |            |             |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 16.7       | 18.4        | 12.045     |
| Glass                                              | kg     | 3.325      |             |            |
| Hinge (2X)                                         | kg     | 0.76       | 0.34        | 1.95       |
| Latch & Lock                                       | kg     | 1.075      | Striker     | 0.5        |
| Doorcheck                                          | kg     | 0.155      |             |            |
| Window regulator / Superplug                       | kg     | 2.01       |             |            |
| Type of Window regulator                           |        | crossarm   |             |            |
| Exterior rear Console                              | kg     |            |             | 0.8        |
| Mirror                                             | kg     | 0.76       |             |            |
| Trim / Insulation                                  | kg     | 3.15       | 0.675       | no         |
| Sealing                                            | kg     | 1.45       | 0.26        | on Body    |
| Wiring Harness                                     | kg     | 0.735      |             |            |
| Weight of Speaker                                  | kg     | 0.675      |             |            |
| Sum electric components                            | kg     | 1.41       |             |            |
| Weight Complete                                    | kg     | 32.75      | 19.3        | 13.45      |
| Q = BIW / Complete                                 |        | 0.51       | 0.95        | 0.90       |
| Mass / Surface                                     | kg/sqm | 21.14      | 10.82       | 11.36      |
| <b>Dimensions</b>                                  |        |            |             |            |
| Length (X)                                         | mm     | 1060       | 1145        | 860        |
| Height (Z)                                         | mm     | 1170       |             |            |
| Width (Y)                                          | mm     |            | 1490        | 1215       |
| True Surface Area Calculated                       | sqm    | 0.79       | 1.70        | 1.06       |
| Depth with / without Trim                          | mm     | 125/210    |             |            |
| Material thickness inner / outer panel             | mm     | 0.74 / 0.7 | 0.66 / 0.7  | 0.66/0.7   |
| Material thickness Glass                           | mm     | 4          |             |            |
| Curvature Glass                                    | mm     | 25         |             |            |
| Beltline / Bottom                                  | mm     | 645        |             |            |
| Hinge / Hinge (Hingespread)                        | mm     | 355        | 1415        | 1145       |
| Length / Hingespread Ratio                         |        | 3.0        | 0.8         | 0.8        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 985/95/255 | 1060/Center | 445/Center |
| Material thickness Hinge                           | mm     | 5          | 3.5         | 20x20x2    |
| <b>Specification</b>                               |        |            |             |            |
| Number of Brackets / Reinforcements                |        | 11         | 4           | 3          |
| Number of Parts total                              |        | 14         | 7           | 5          |
| Number of Weldspots                                |        | 69         | 23          | 14         |
| Area / Thickness of Side Intrusion Beam            |        | 0 / 3      |             |            |
| Length of Side Intrusion Beam                      | mm     | 880/930    |             |            |
| Inertia of Side Intrusion Beam                     | mm     | 29040      |             |            |
| Attachment Type of Side Intrusion Beam             |        | spotwelded |             |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - VW Golf**

| Closure                                            |        | Door   | Hood | Decklid    |
|----------------------------------------------------|--------|--------|------|------------|
| <b>Weight</b>                                      |        |        |      |            |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     |        |      | 8.13       |
| Glass                                              | kg     |        |      |            |
| Hinge (2X)                                         | kg     |        |      | N/A        |
| Latch & Lock                                       | kg     |        |      |            |
| Doorcheck                                          | kg     |        |      |            |
| Window regulator / Superplug                       | kg     |        |      |            |
| Type of Window regulator                           |        |        |      |            |
| Exterior rear Console                              | kg     |        |      |            |
| Mirror                                             | kg     |        |      |            |
| Trim / Insulation                                  | kg     |        |      |            |
| Sealing                                            | kg     |        |      |            |
| Wiring Harness                                     | kg     |        |      |            |
| Weight of Speaker                                  | kg     |        |      |            |
| Sum electric components                            | kg     |        |      |            |
| Weight Complete                                    | kg     |        |      | 0.00       |
| Q = BIW / Complete                                 |        |        |      |            |
| Mass / Surface                                     | kg/sqm | kg/sqm |      | 12.47      |
| <b>Dimensions</b>                                  |        |        |      |            |
| Length (X)                                         | mm     |        |      | 930        |
| Height (Z)                                         | mm     |        |      |            |
| Width (Y)                                          | mm     |        |      | 1335       |
| True Surface Area Calculated                       | sqm    |        |      | 0.65       |
| Depth with / without Trim                          | mm     |        |      |            |
| Material thickness inner / outer panel             | mm     |        |      | 0.63/0.681 |
| Material thickness Glass                           | mm     |        |      |            |
| Curvature Glass                                    | mm     |        |      |            |
| Beltline / Bottom                                  | mm     |        |      |            |
| Hinge / Hinge (Hingespread)                        | mm     |        |      | 660        |
| Length / Hingespread Ratio                         |        |        |      | 1.4        |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     |        |      | 790/Center |
| Material thickness Hinge                           | mm     |        |      |            |
| <b>Specification</b>                               |        |        |      |            |
| Number of Brackets / Reinforcements                |        |        |      | 3          |
| Number of Parts total                              |        |        |      | 5          |
| Number of Weldspots                                |        |        |      | 65         |
| Area / Thickness of Side Intrusion Beam            |        |        |      |            |
| Length of Side Intrusion Beam                      | mm     |        |      |            |
| Inertia of Side Intrusion Beam                     | mm     |        |      |            |
| Attachment Type of Side Intrusion Beam             |        |        |      |            |





# Benchmarking

## **Data Gathering - Teardown of Closures Results Sheet - VW Passat**

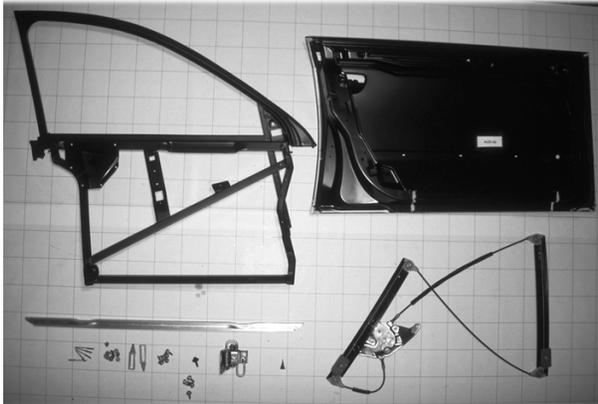
| <b>Closure</b>                                     |        | <b>Door</b> | <b>Hood</b> | <b>Decklid</b> |
|----------------------------------------------------|--------|-------------|-------------|----------------|
| <b>Weight</b>                                      |        |             |             |                |
| BIW (Bracket, Reinf., Side Intrusion Beam)         | kg     | 16.7        | 14.9        | 9.45           |
| Glass                                              | kg     |             |             |                |
| Hinge (2X)                                         | kg     | 1.76        |             |                |
| Latch & Lock                                       | kg     | 0.765       |             |                |
| Doorcheck                                          | kg     |             |             |                |
| Window regulator / Superplug                       | kg     | 3.4         |             |                |
| Type of Window regulator                           |        | crossarm    |             |                |
| Exterior rear Console                              | kg     |             |             |                |
| Mirror                                             | kg     |             |             |                |
| Trim / Insulation                                  | kg     |             |             |                |
| Sealing                                            | kg     |             |             |                |
| Wiring Harness                                     | kg     |             |             |                |
| Weight of Speaker                                  | kg     | 0.55        |             |                |
| Sum electric components                            | kg     |             |             |                |
| Weight Complete                                    | kg     |             |             |                |
| Q = BIW / Complete                                 |        |             |             |                |
| Mass / Surface                                     | kg/sqm | 20.12       | 9.25        | 12.60          |
| <b>Dimensions</b>                                  |        |             |             |                |
| Length (X)                                         | mm     | 1100        | 1415        | 780            |
| Height (Z)                                         | mm     | 1160        |             |                |
| Width (Y)                                          | mm     |             | 1525        | 1200           |
| True Surface Area Calculated                       | sqm    | 0.83        | 1.61        | 0.75           |
| Depth with / without Trim                          | mm     | 0/145       |             |                |
| Material thickness inner / outer panel             | mm     | 0.8/0.72    | 0.7/0.8     | 0.8/1          |
| Material thickness Glass                           | mm     | 4           |             |                |
| Curvature Glass                                    | mm     | N/A         |             |                |
| Beltline / Bottom                                  | mm     | 100         |             |                |
| Hinge / Hinge (Hingespread)                        | mm     | 310         | 1400        | 1145           |
| Length / Hingespread Ratio                         |        | 3.5         | 1.0         | 0.7            |
| Hinge / Latch (horizontal / vertical / upr / lwr ) | mm     | 1015/70/240 | 1085/Center | 490/Center     |
| Material thickness Hinge                           | mm     | 3.9         | 4           | 4              |
| <b>Specification</b>                               |        |             |             |                |
| Number of Brackets / Reinforcements                |        | 10          | 6           | 3              |
| Number of Parts total                              |        | 12          | 8           | 5              |
| Number of Weldspots                                |        | 113         | 110         | 27             |
| Area / Thickness of Side Intrusion Beam            |        | 0 / 1.8     |             |                |
| Length of Side Intrusion Beam                      | mm     | 1035        |             |                |
| Inertia of Side Intrusion Beam                     | mm     | 15005       |             |                |
| Attachment Type of Side Intrusion Beam             |        | spotwelded  |             |                |





# Benchmarking

## *Photos - Audi A6*



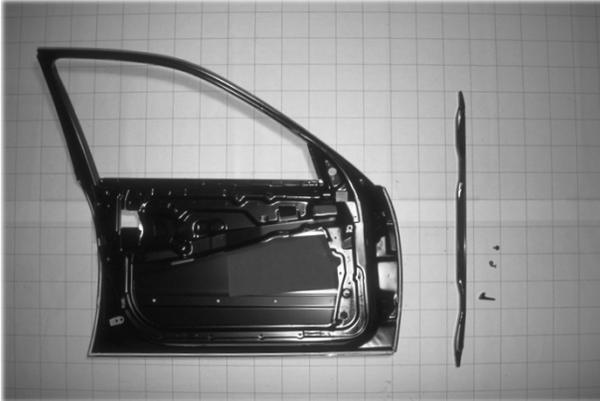
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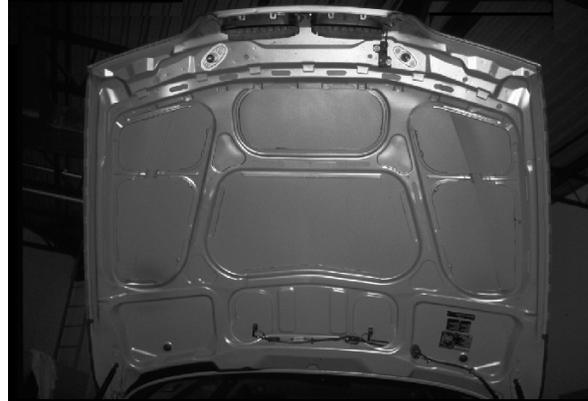


# Benchmarking

## *Photos - BMW 528i*



*Door*



*Hood*



*Hood*





# Benchmarking

## *Photos - Cadillac Sedan Deville*



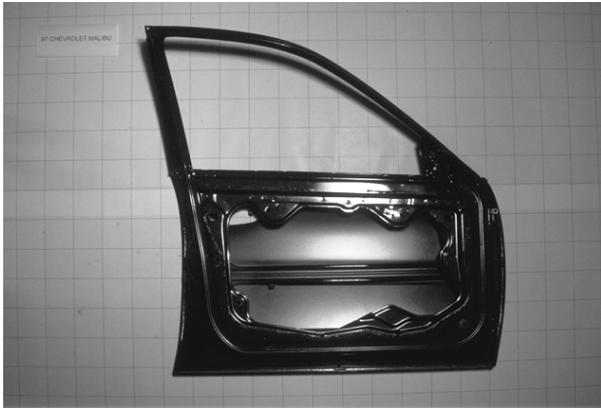
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# Benchmarking

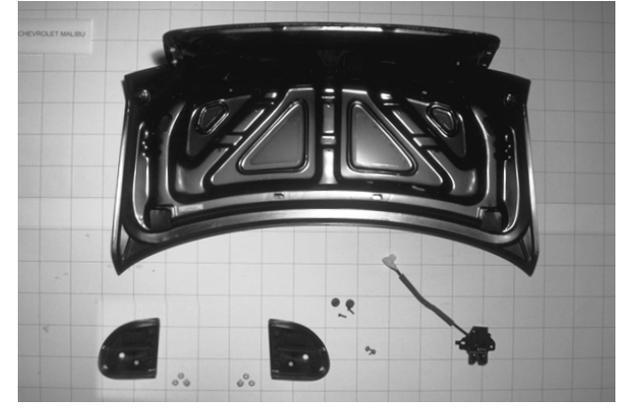
## *Photos - Chevrolet Malibu*



*Door*



*Hood*



*Decklid*



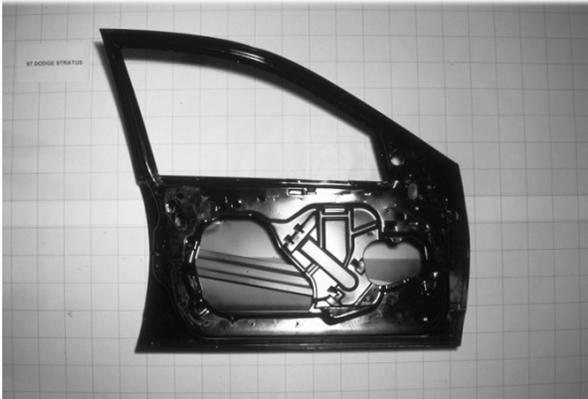
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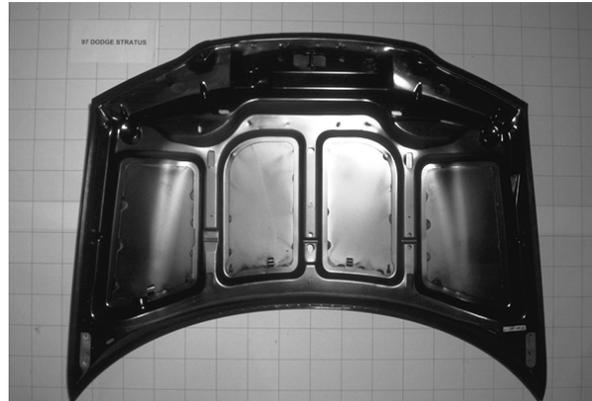


# Benchmarking

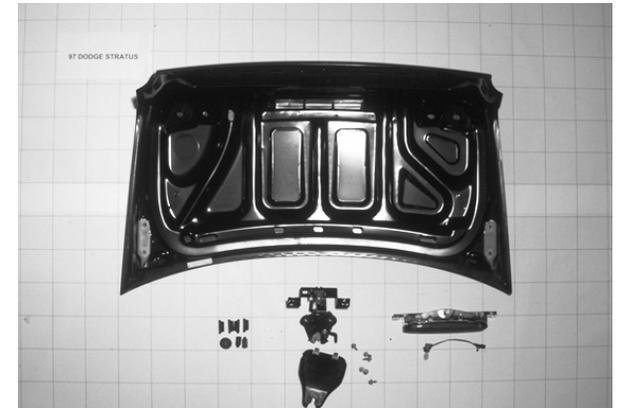
## *Photos - Dodge Stratus*



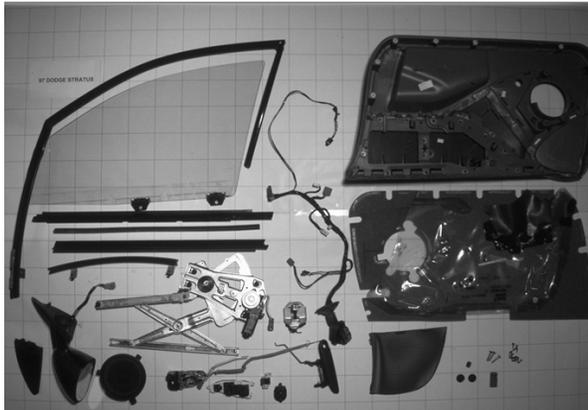
*Door*



*Hood*



*Decklid*



*Door*



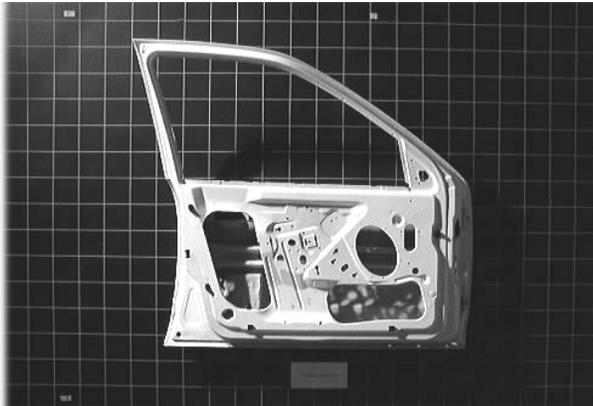
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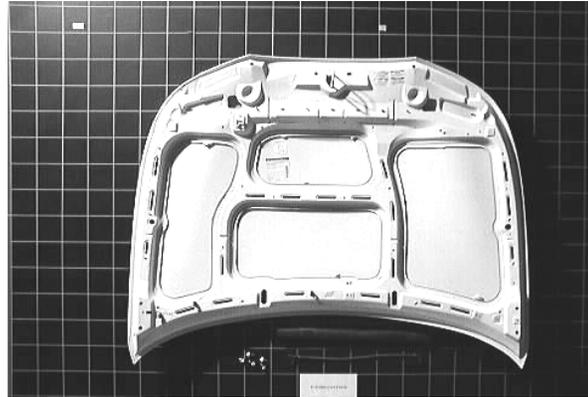


# Benchmarking

## *Photos - Ford Contour*



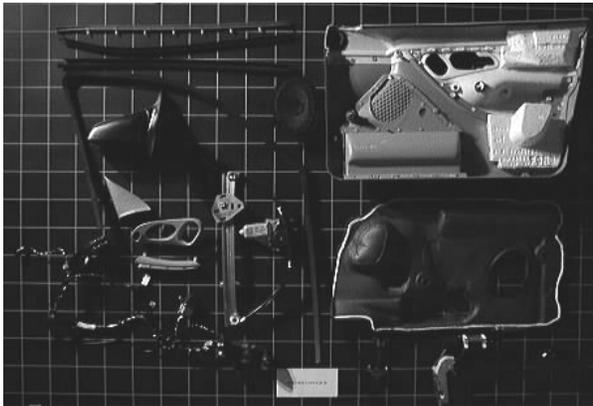
*Door*



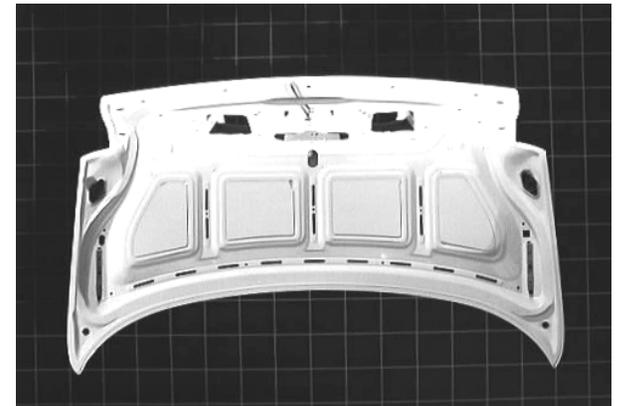
*Hood*



*Decklid*



*Door*



*Decklid*



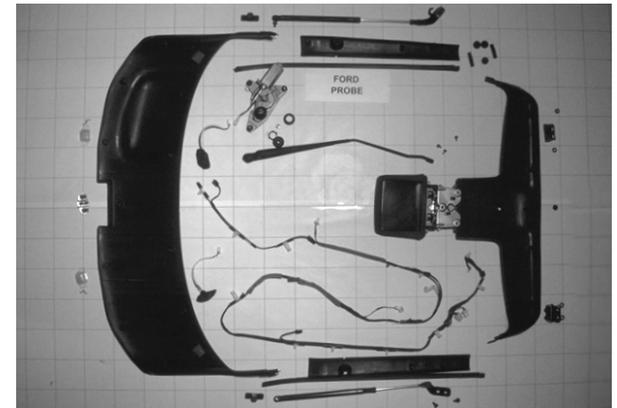


# Benchmarking

## *Photos - Ford Probe*



*Hatchback*



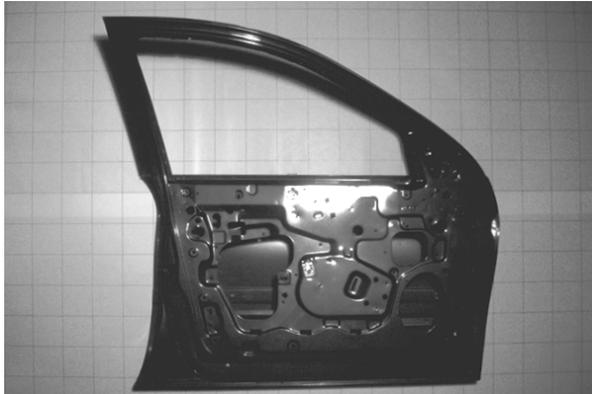
*Hatchback*



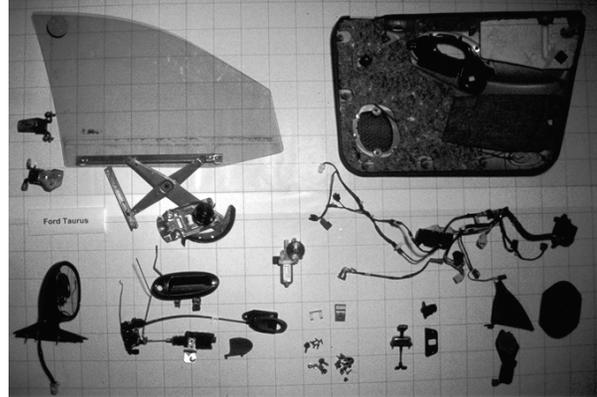


# Benchmarking

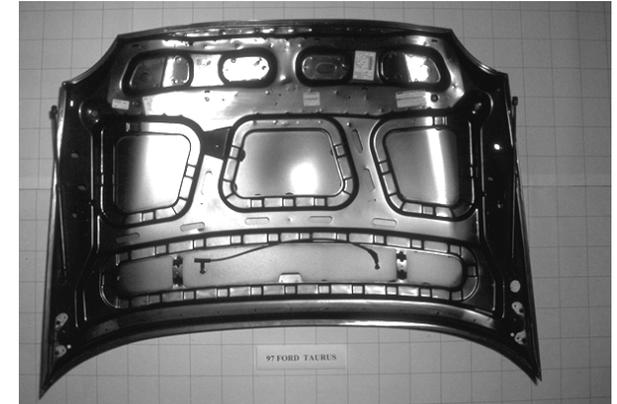
## *Photos - Ford Taurus*



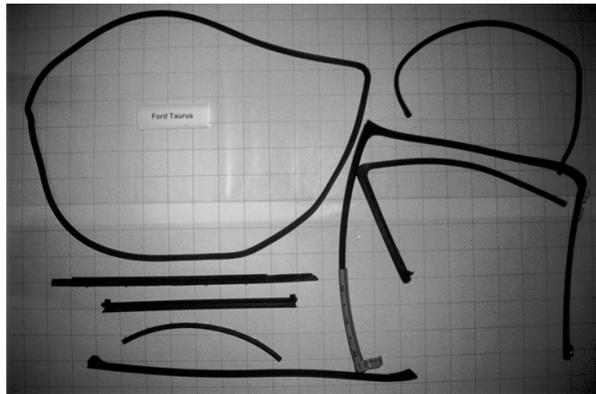
*Door*



*Door*



*Hood*



*Door*



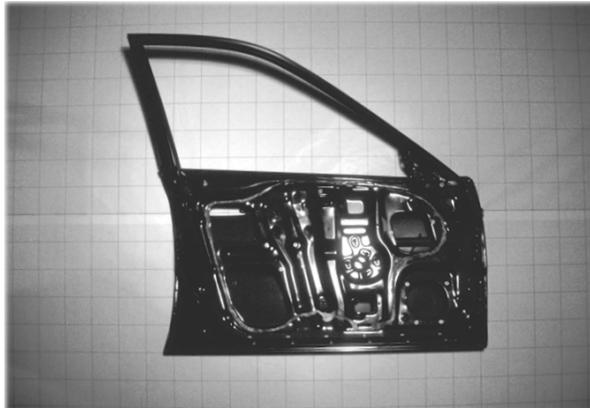
*Decklid*





# Benchmarking

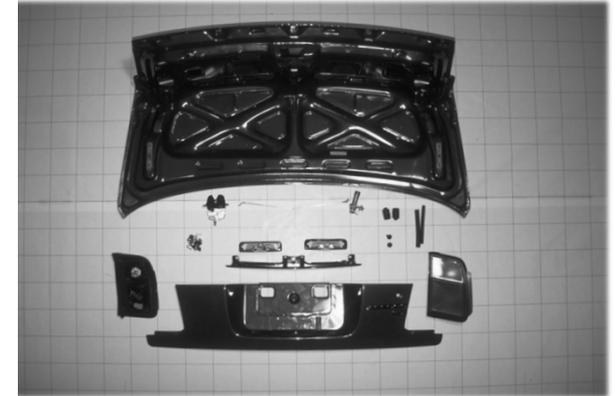
## *Photos - Honda Accord*



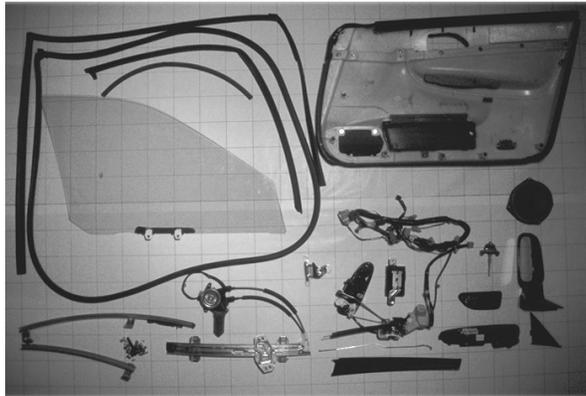
*Door*



*Hood*



*Decklid*



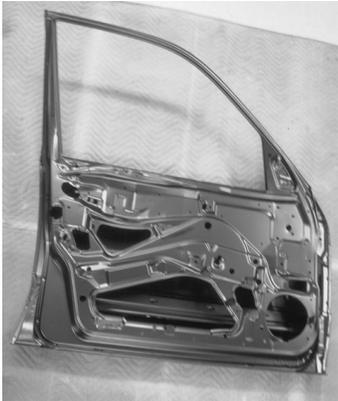
*Door*



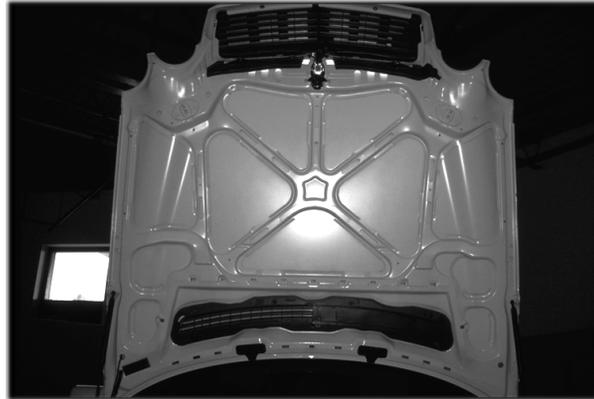


# Benchmarking

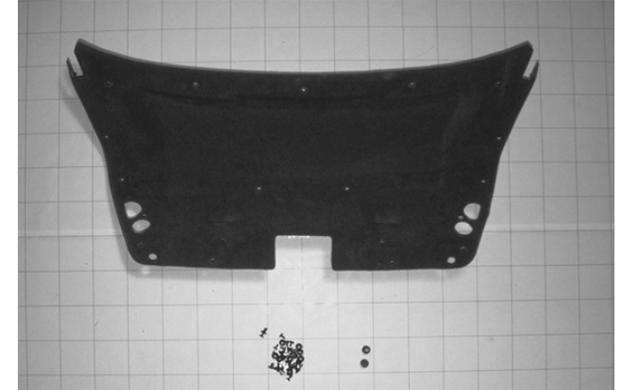
## *Photos - Mercedes E320*



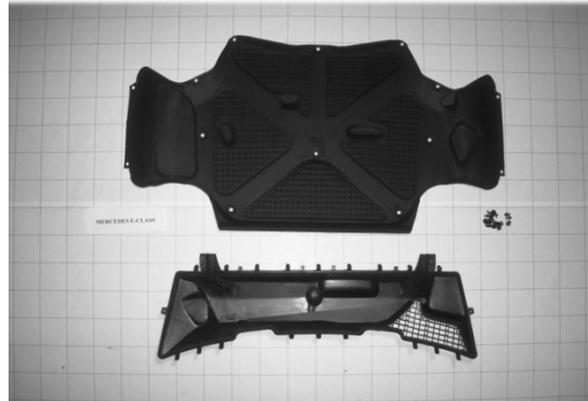
*Door*



*Hood*



*Decklid*



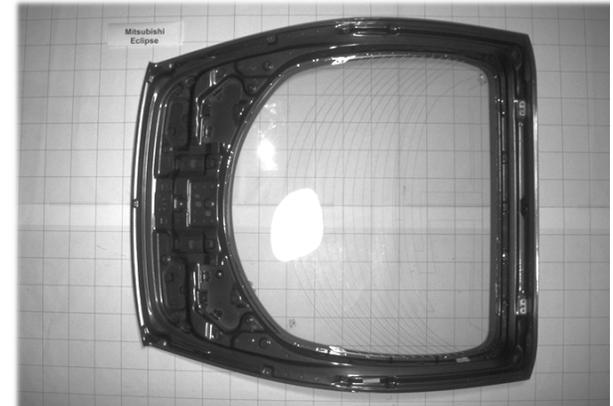
*Hood*



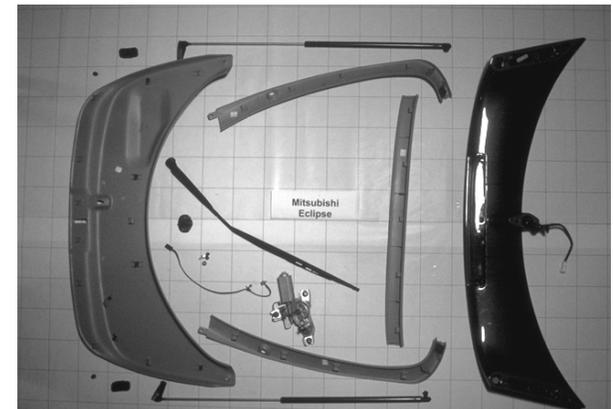


# Benchmarking

## *Photos - Mitsubishi Eclipse*



*Hatchback*



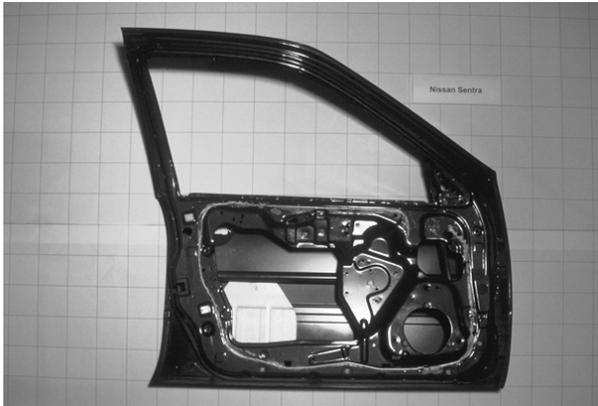
*Hatchback*





# Benchmarking

## *Photos - Nissan Sentra*



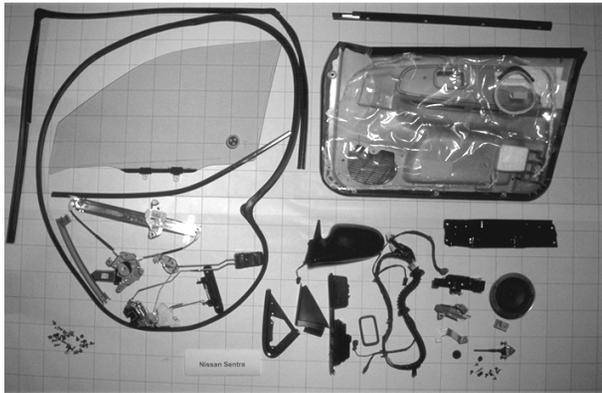
*Door*



*Hood*



*Decklid*



*Door*





# Benchmarking

## Photos - Saturn LS



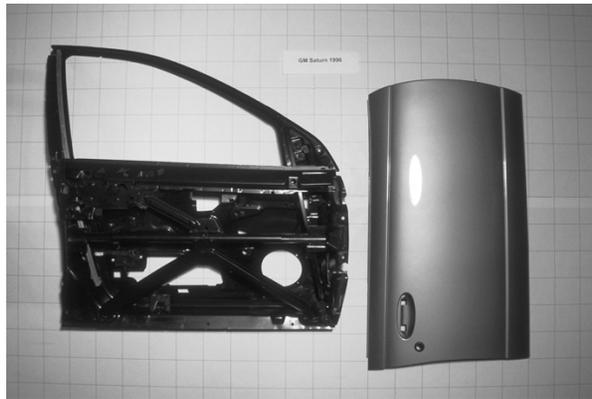
*Door*



*Door*



*Hood*



*Door*



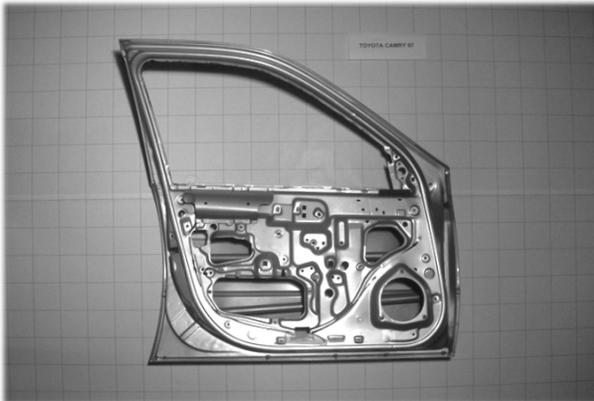
*Decklid*



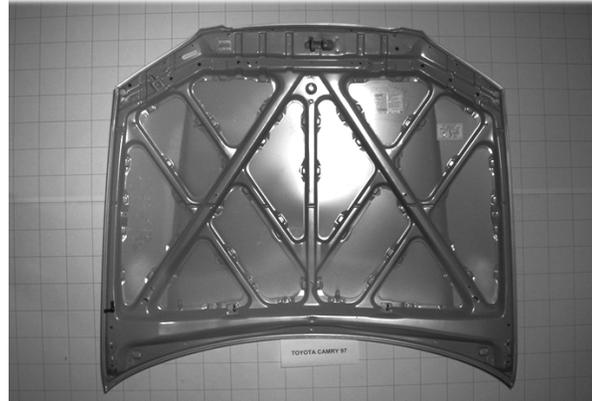


# Benchmarking

## *Photos - Toyota Camry*



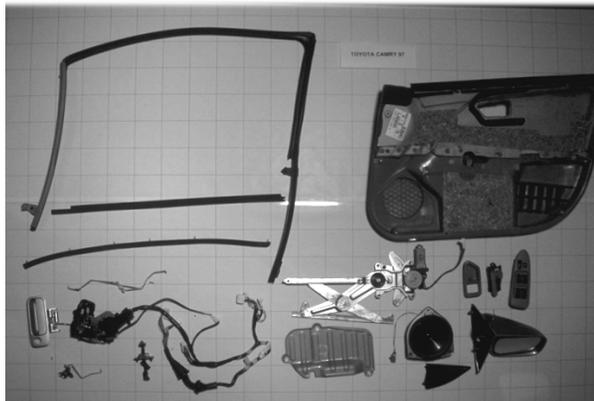
*Door*



*Hood*



*Decklid*



*Door*



*Hood*



*Decklid*



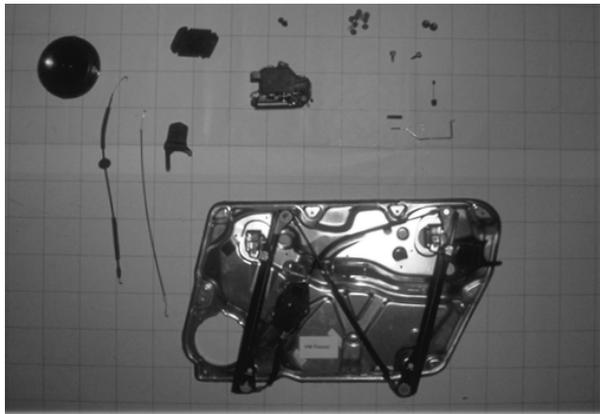


# Benchmarking

## *Photos - VW Passat*



*Door*



*Door*

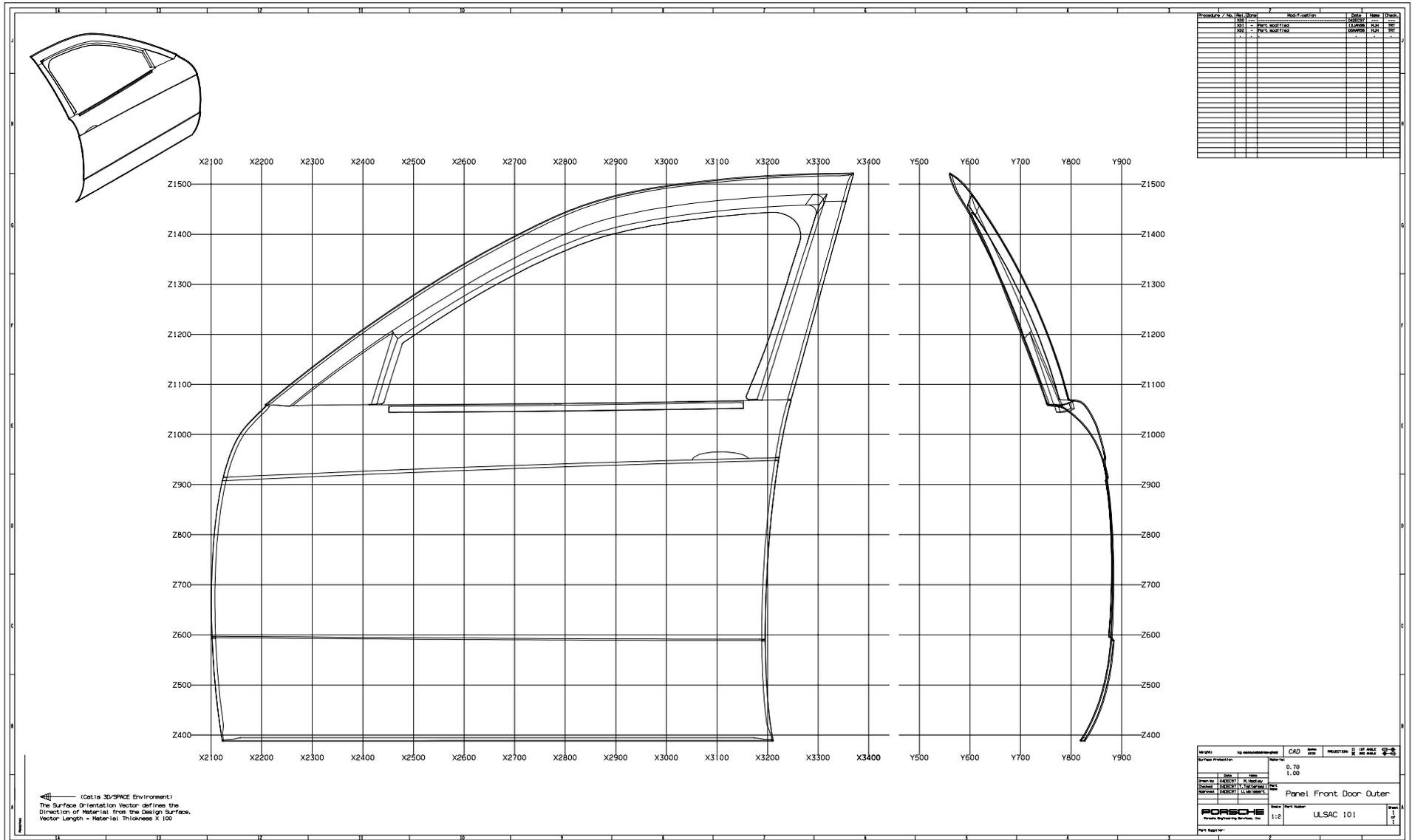






# Part Drawings

## Part 101 - Panel Front Door Outer





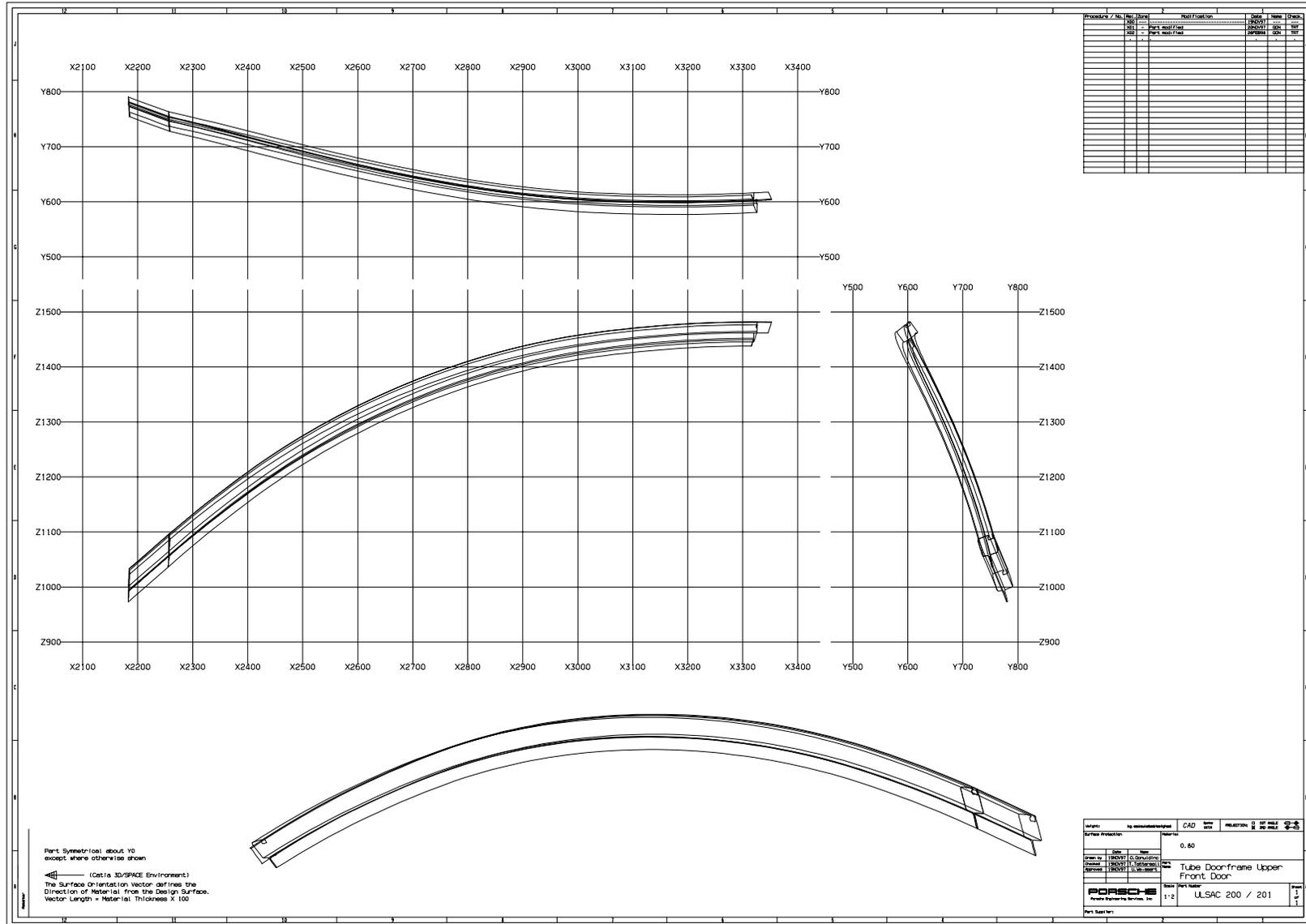






# Part Drawings

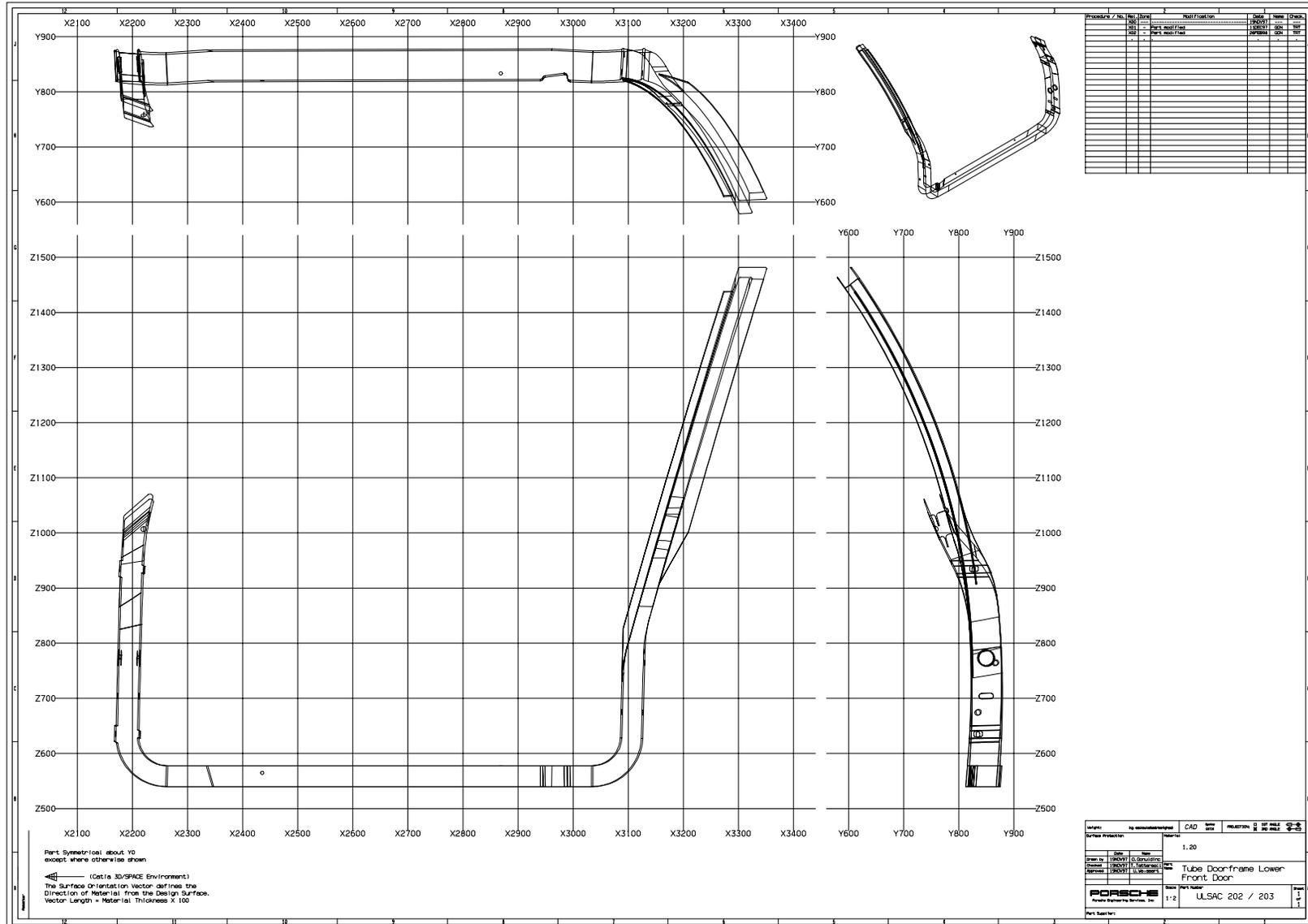
## Part 200 - Tube Doorframe Upper Front Door





# Part Drawings

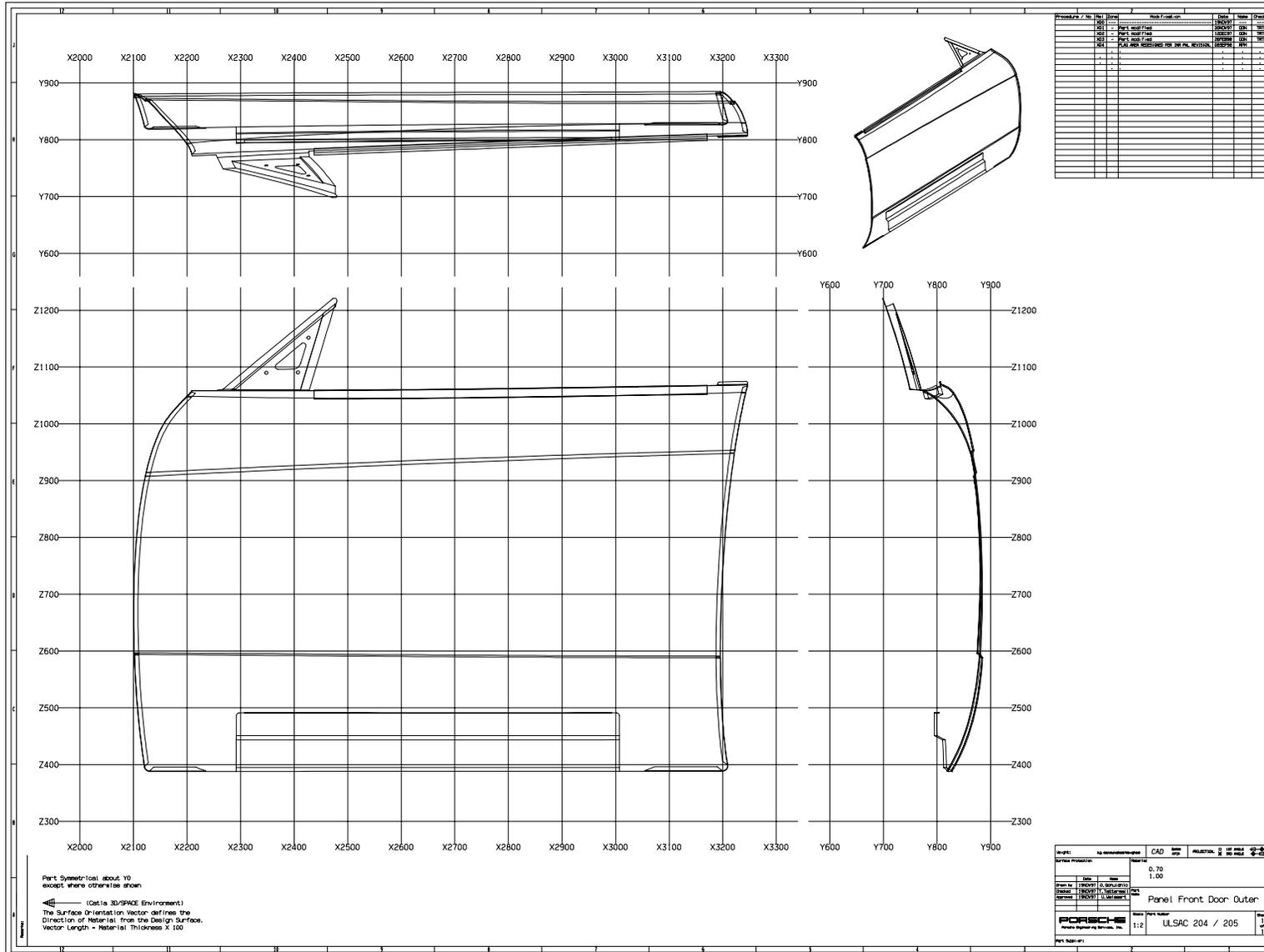
## Part 202 - Tube Doorframe Lower Front Door





# Part Drawings

## Part 204 - Panel Front Door Outer

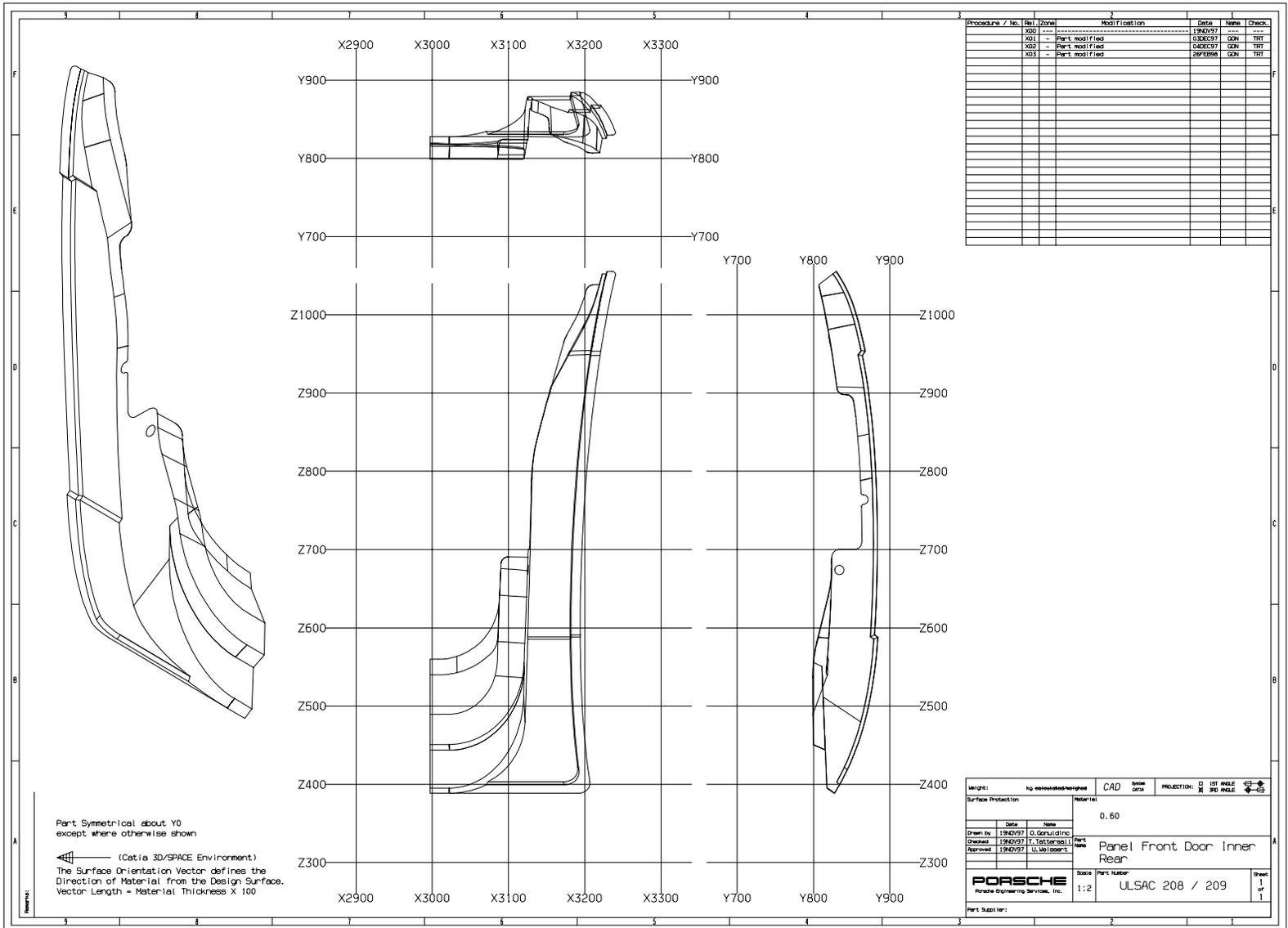






# Part Drawings

## Part 208 - Panel Front Door Inner Rear





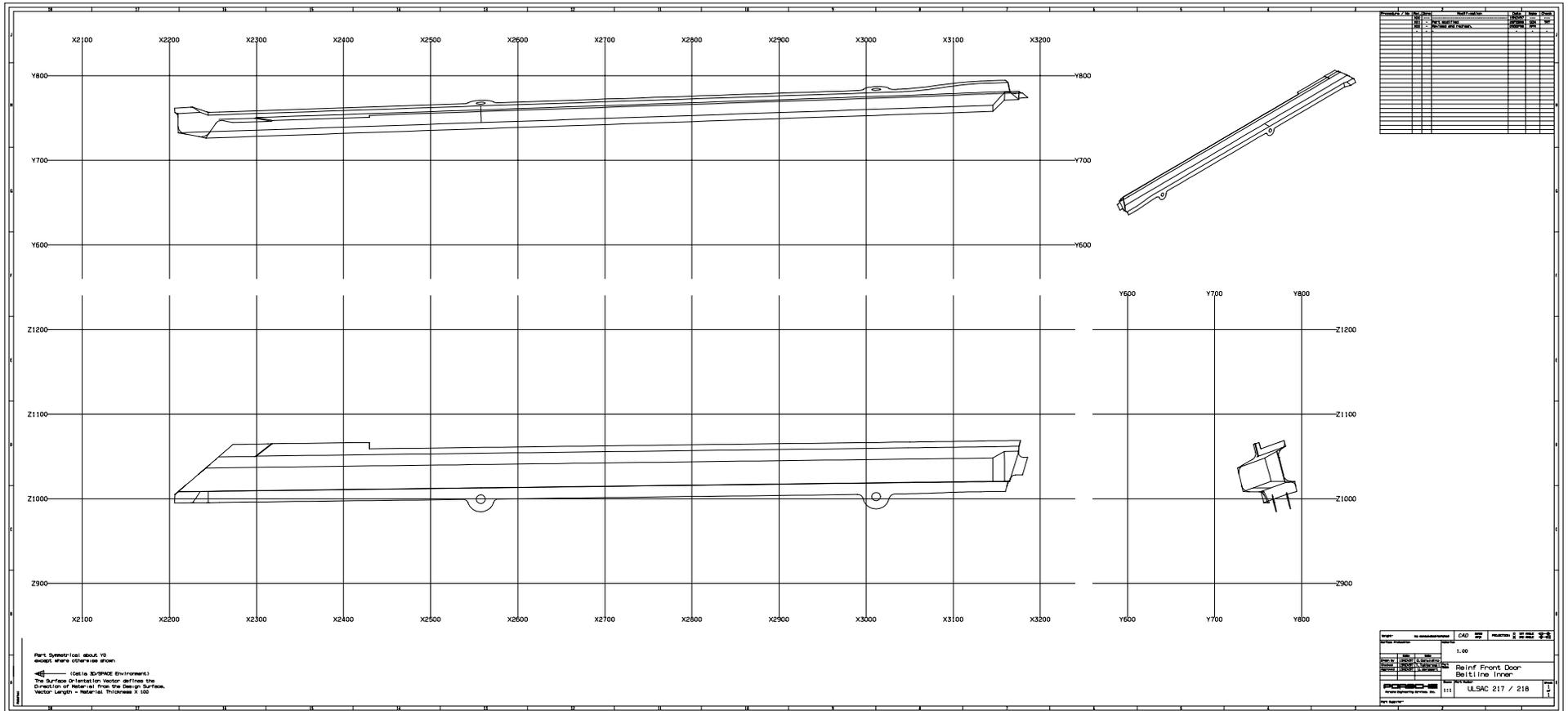






# Part Drawings

## Part 217/218 - Reinforcement Front Door Beltline Inner

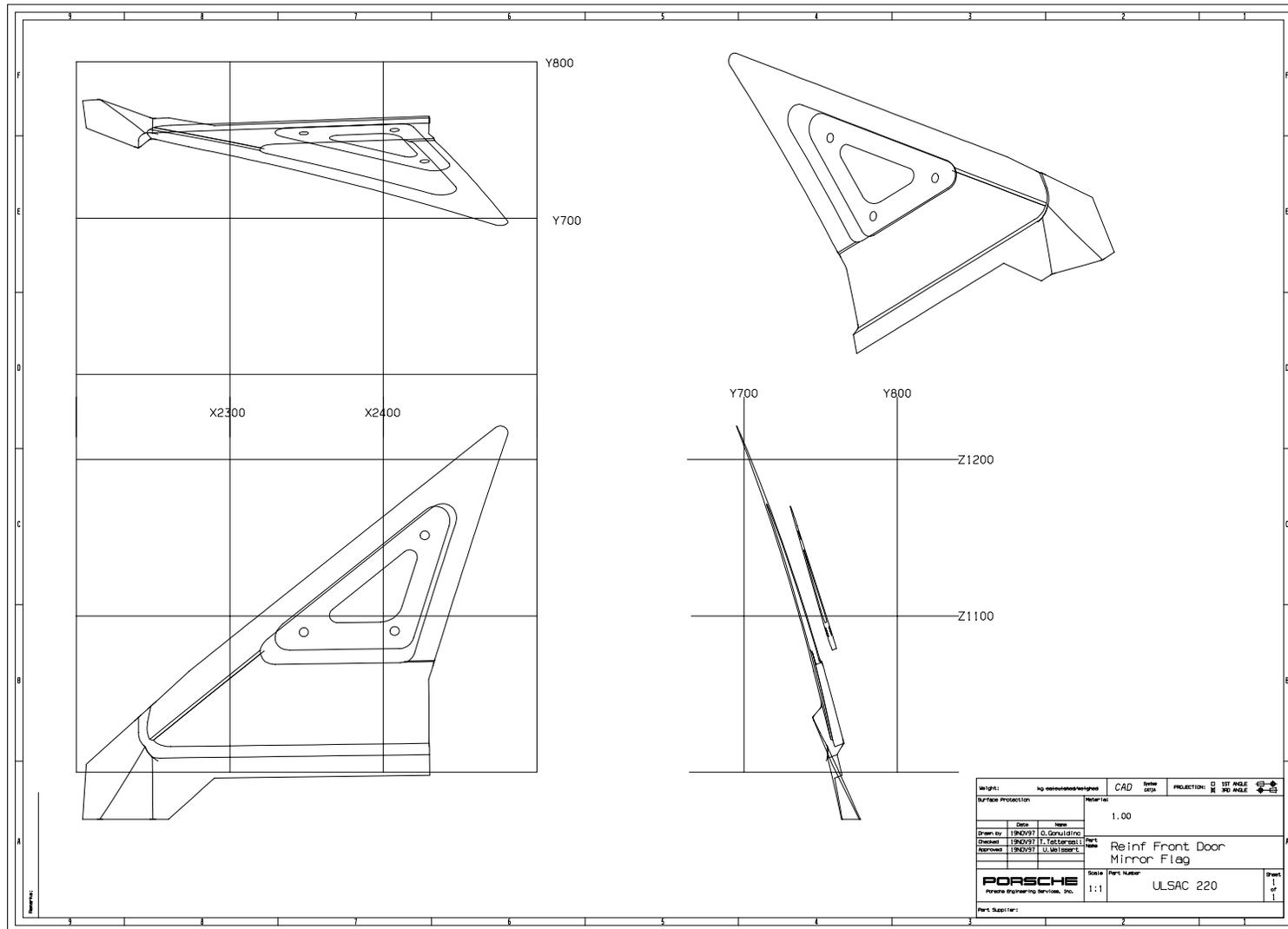






# Part Drawings

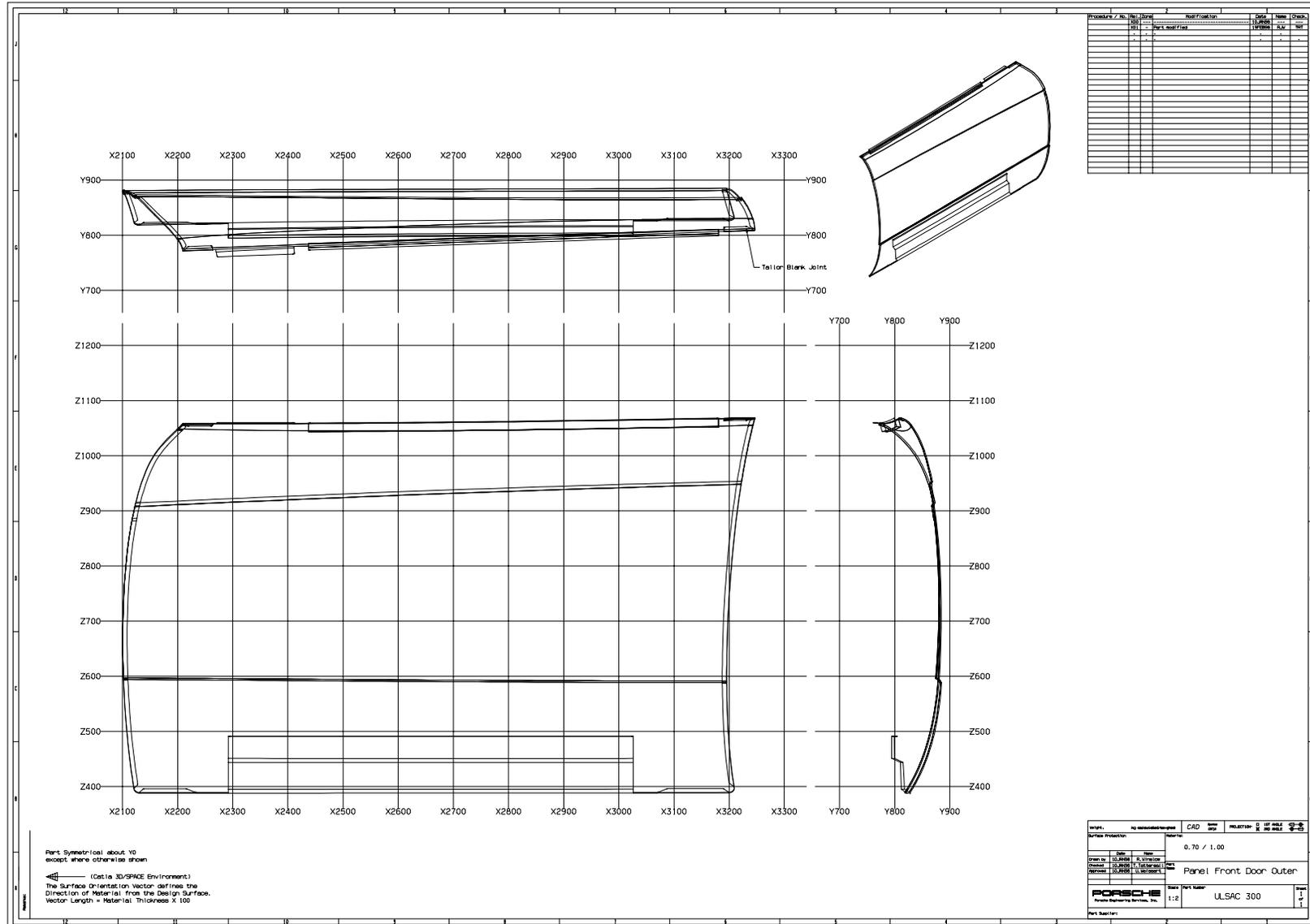
## **Part 220/221 - Reinforcement Front Door Mirror Flag**





# Part Drawings

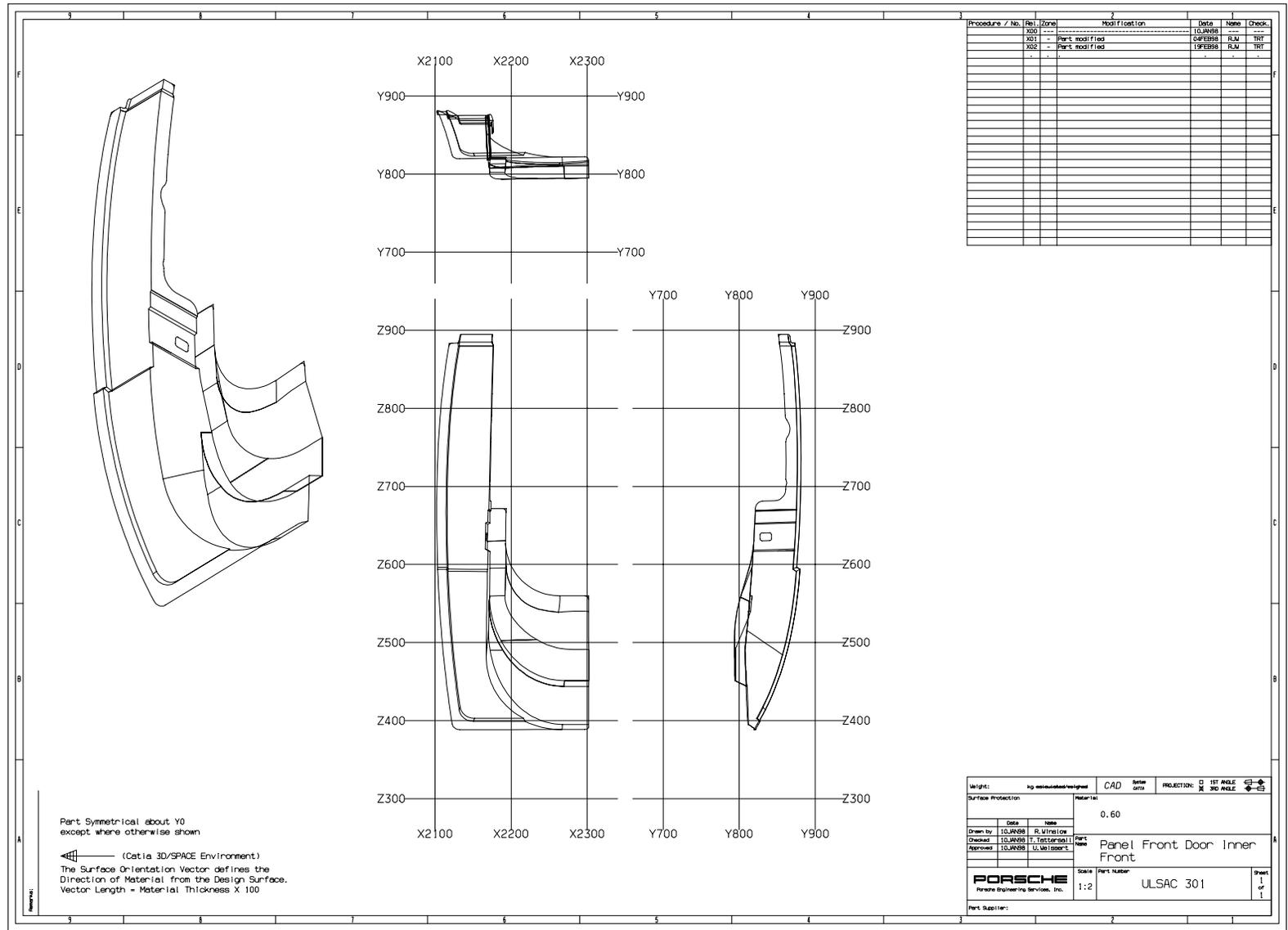
## Part 300 - Panel Front Door Outer





# Part Drawings

## Part 301 - Panel Front Door Inner Front

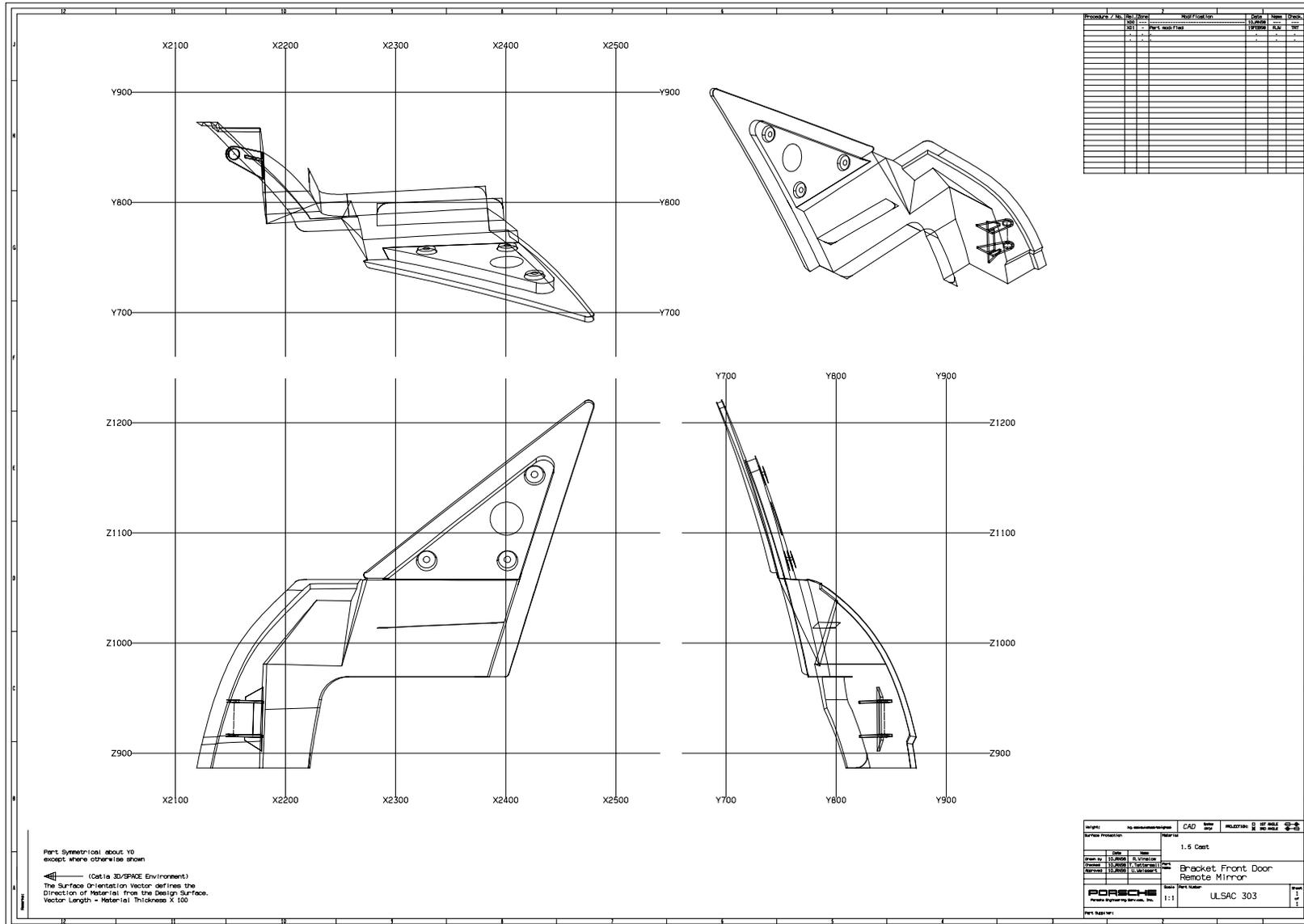






# Part Drawings

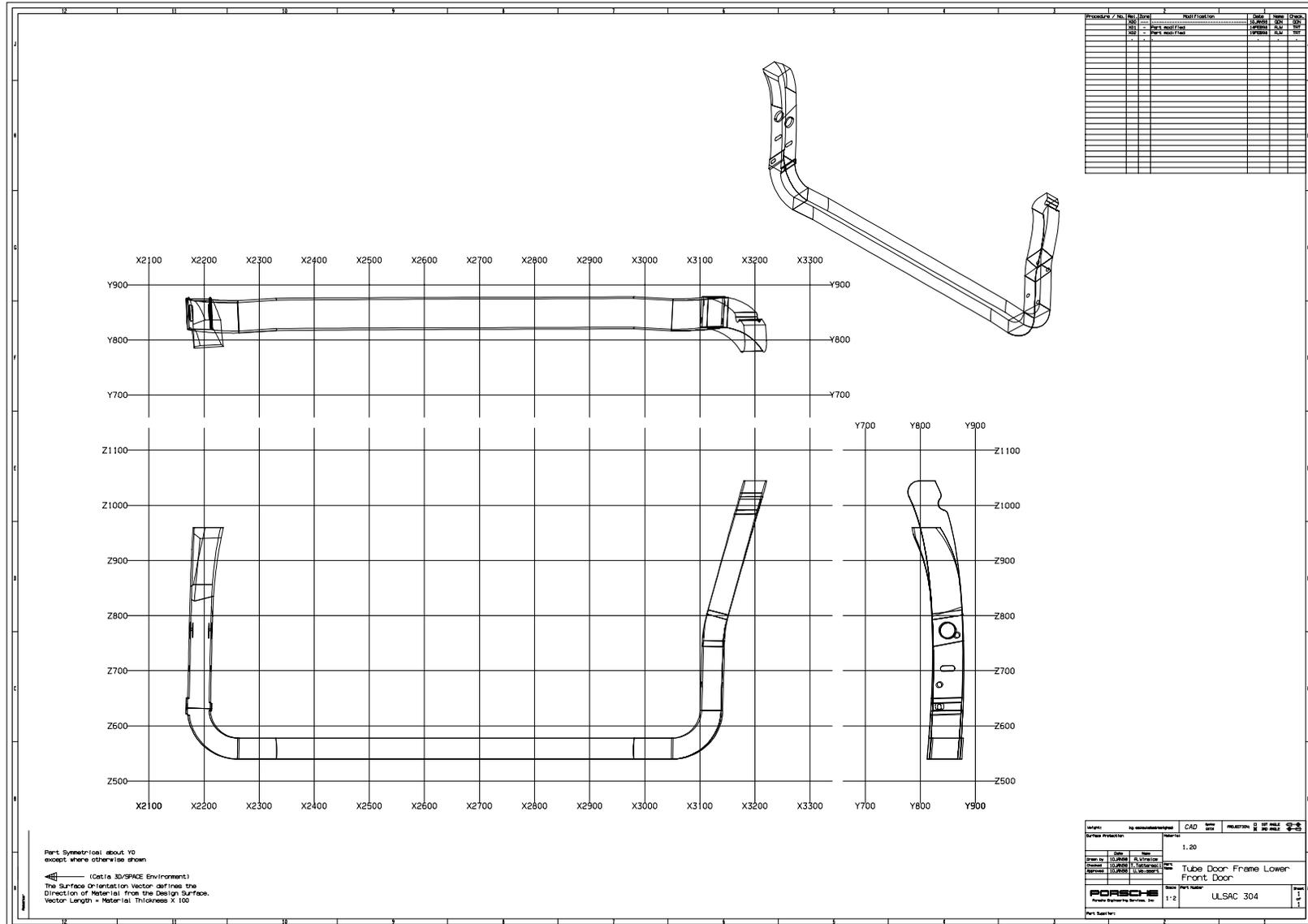
## Part 303 - Bracket Front Door Remote Mirror





# Part Drawings

## Part 304 - Tube Door Frame Lower Front Door

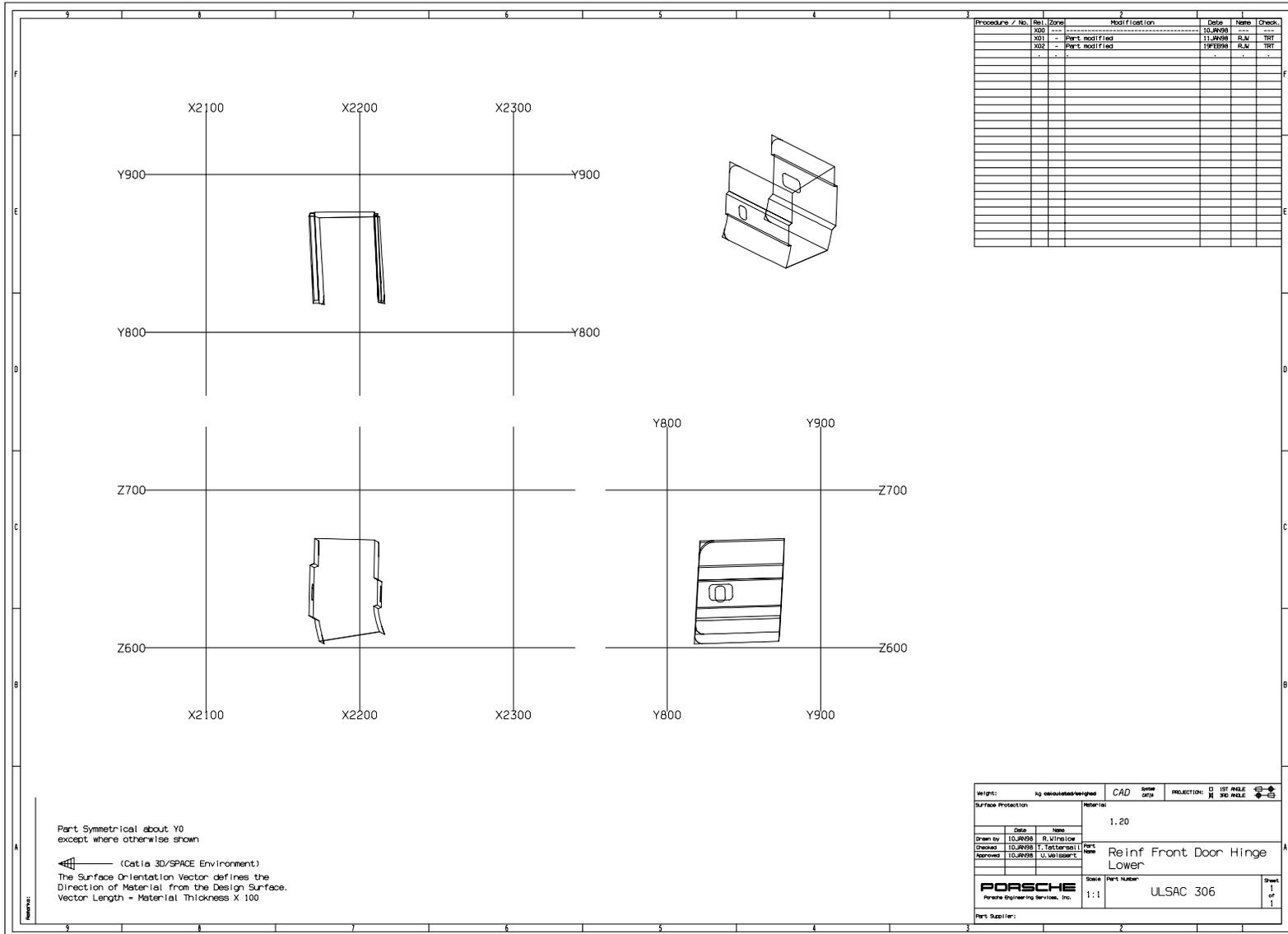






# Part Drawings

## Part 306 - Reinforcement Front Door Hinge Lower



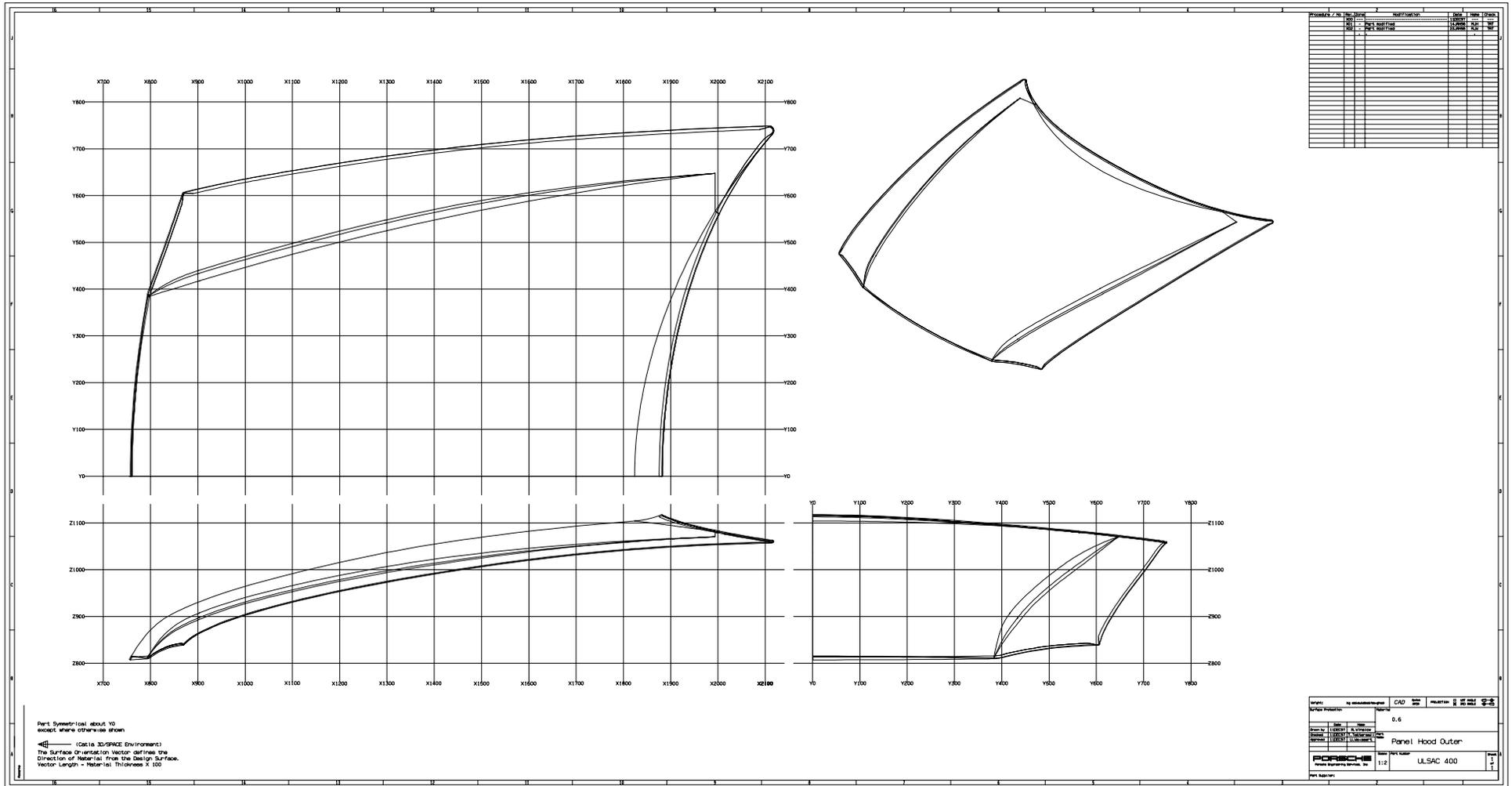






# Part Drawings

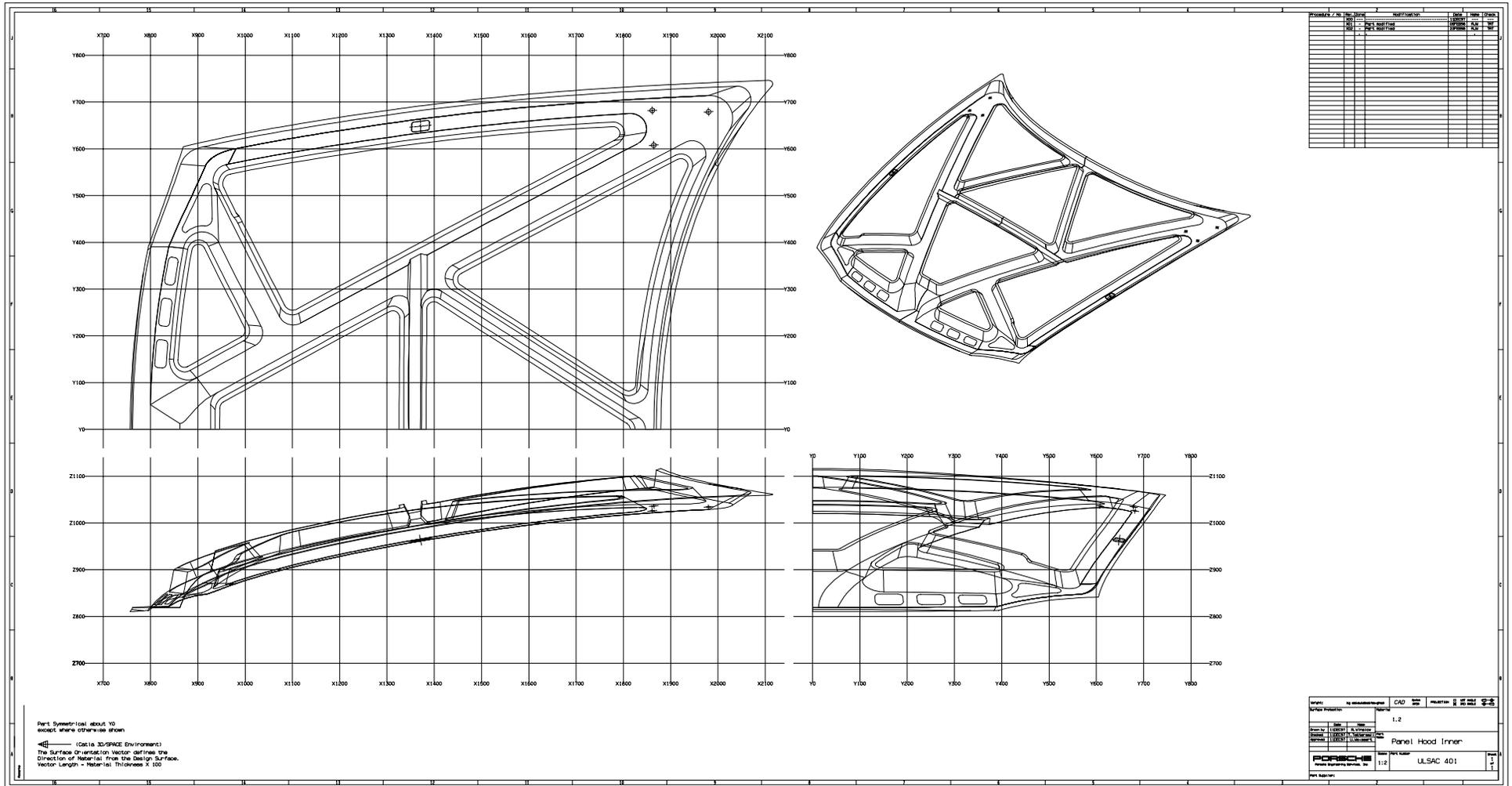
## Part 400 - Panel Hood Outer





# Part Drawings

## Part 401 - Panel Hood Inner



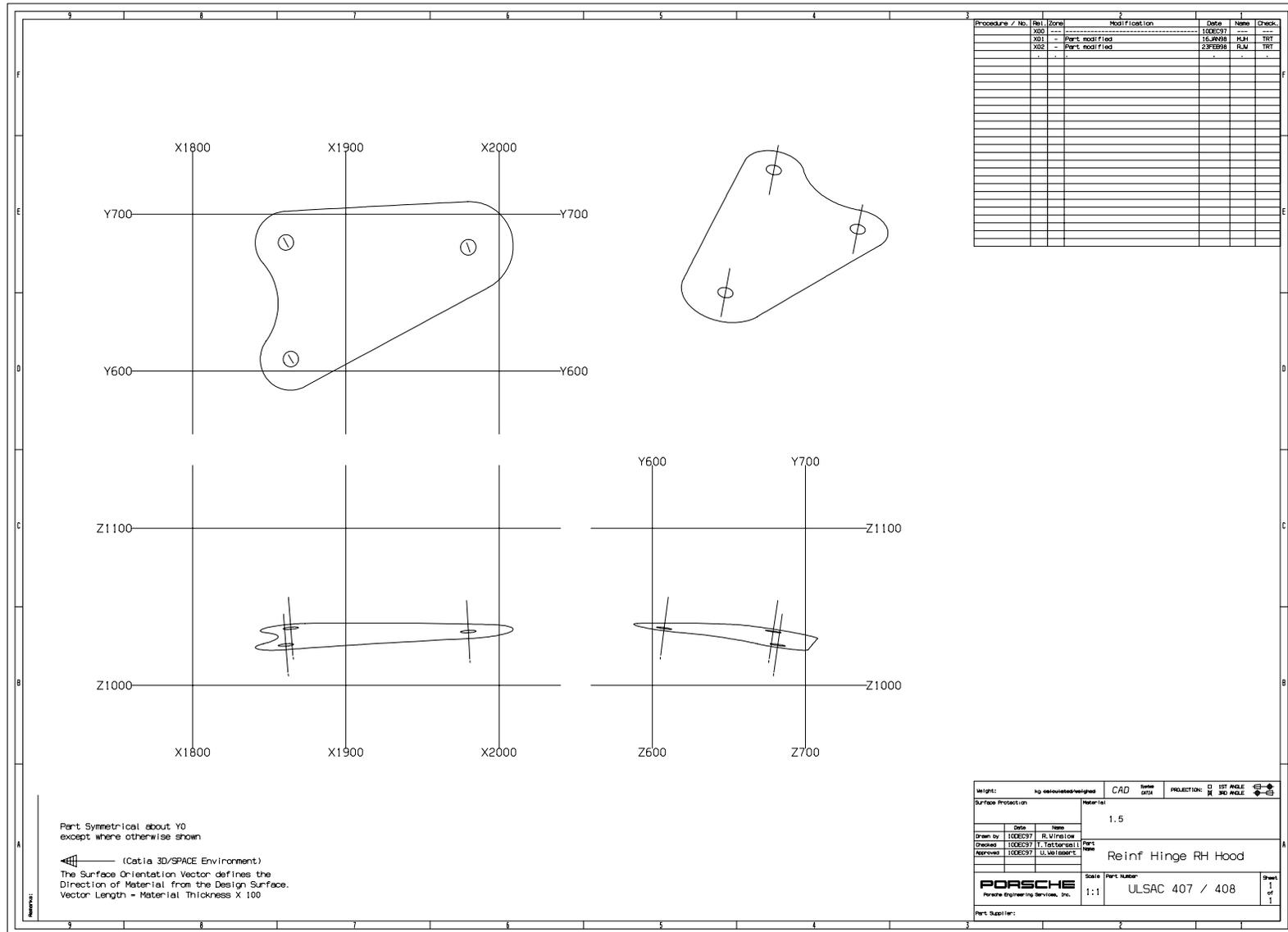






# Part Drawings

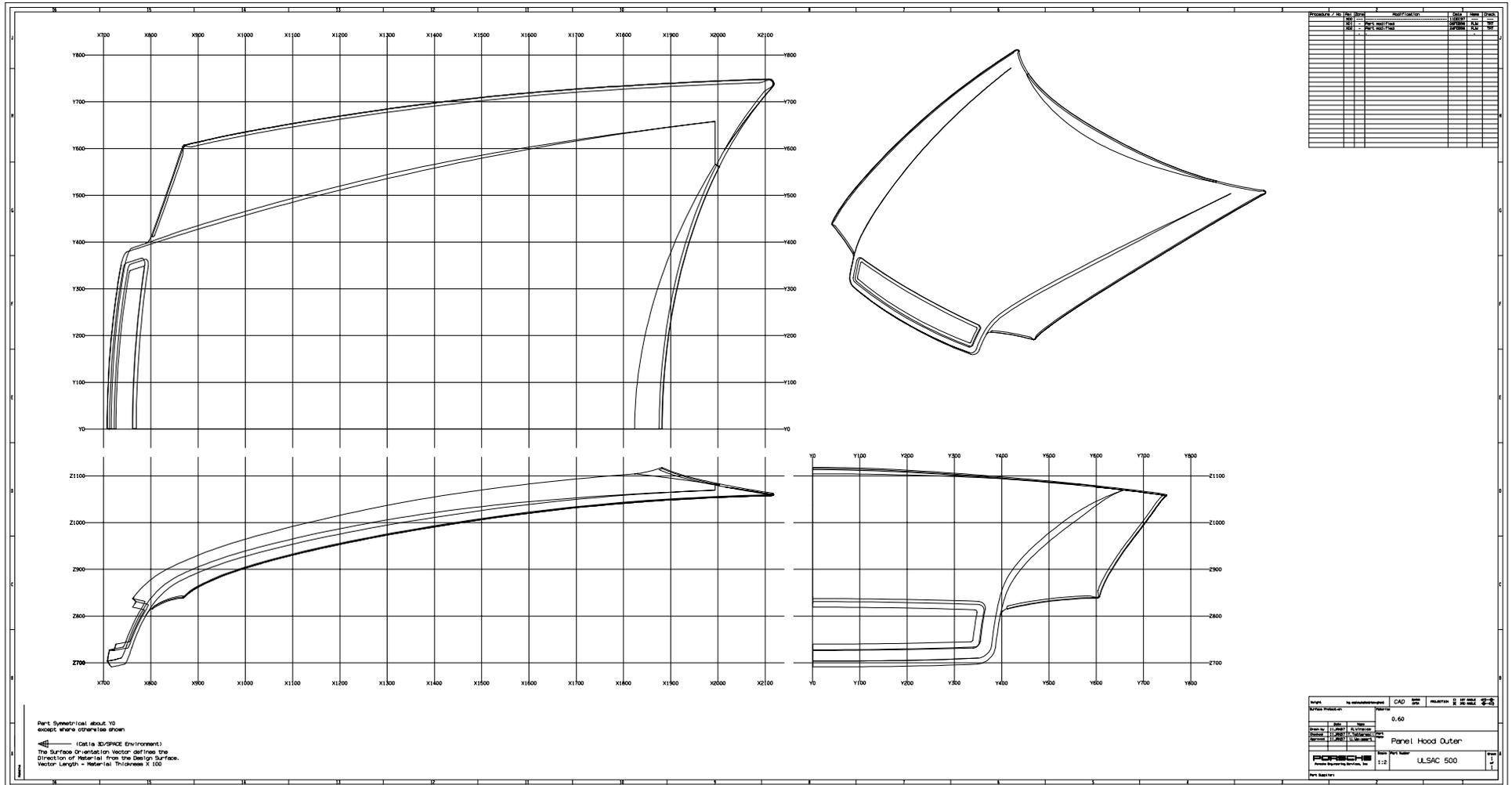
## Part 407/8 - Reinforcement Hinge R/LH Hood





# Part Drawings

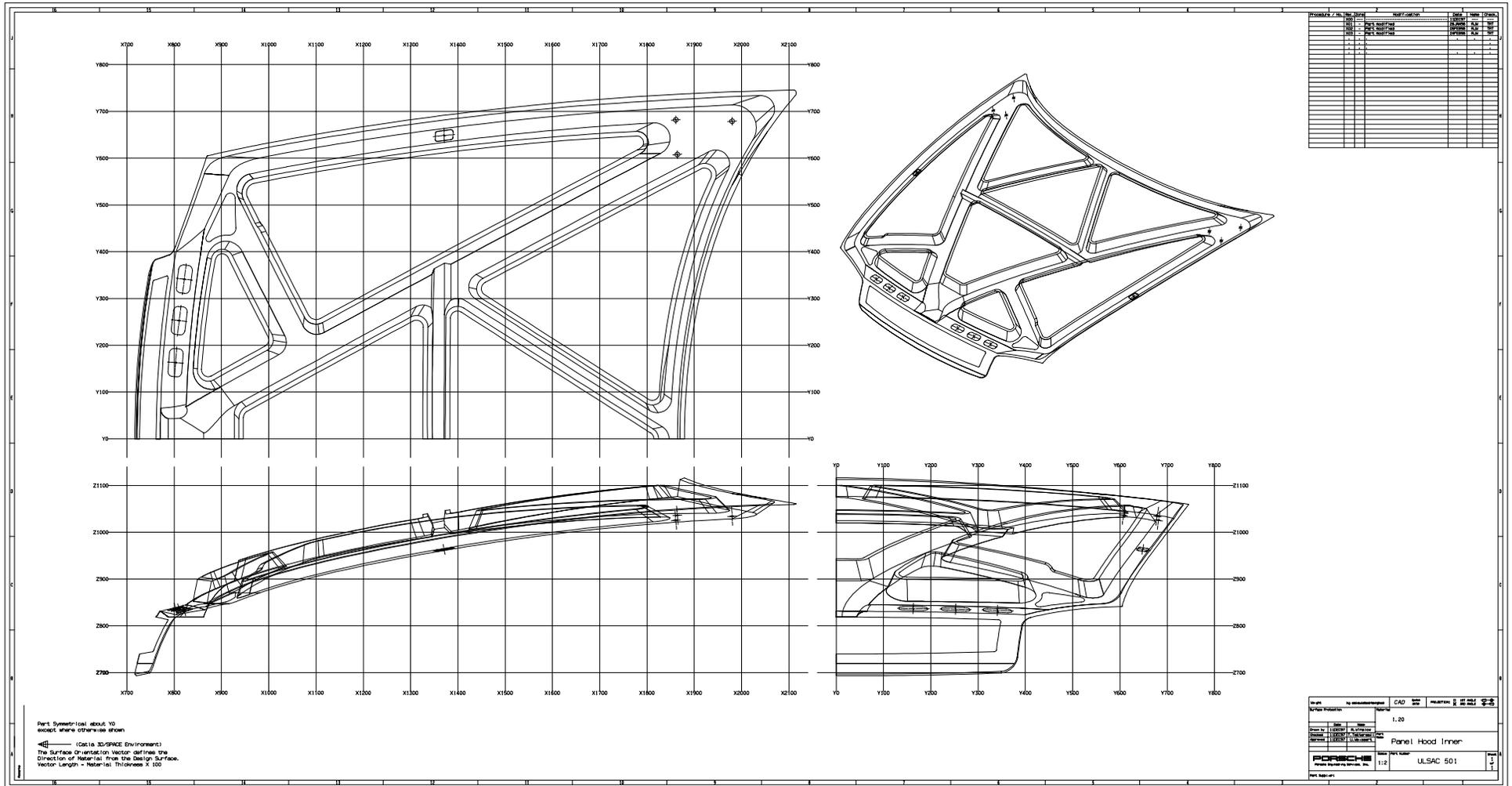
## Part 500 - Panel Hood Outer





# Part Drawings

## Part 501 - Panel Hood Inner



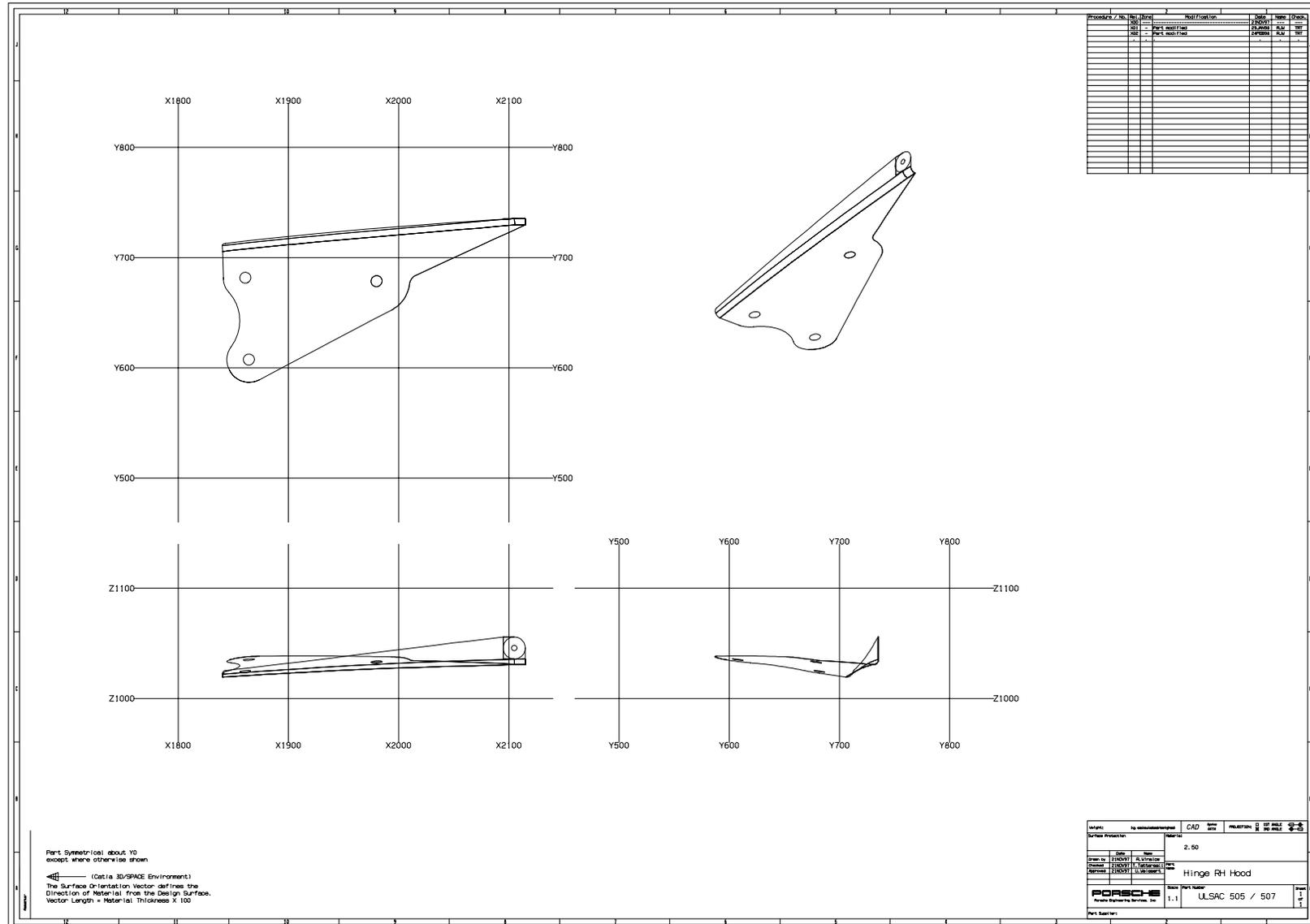






# Part Drawings

## Part 505 - Hinge RH Hood

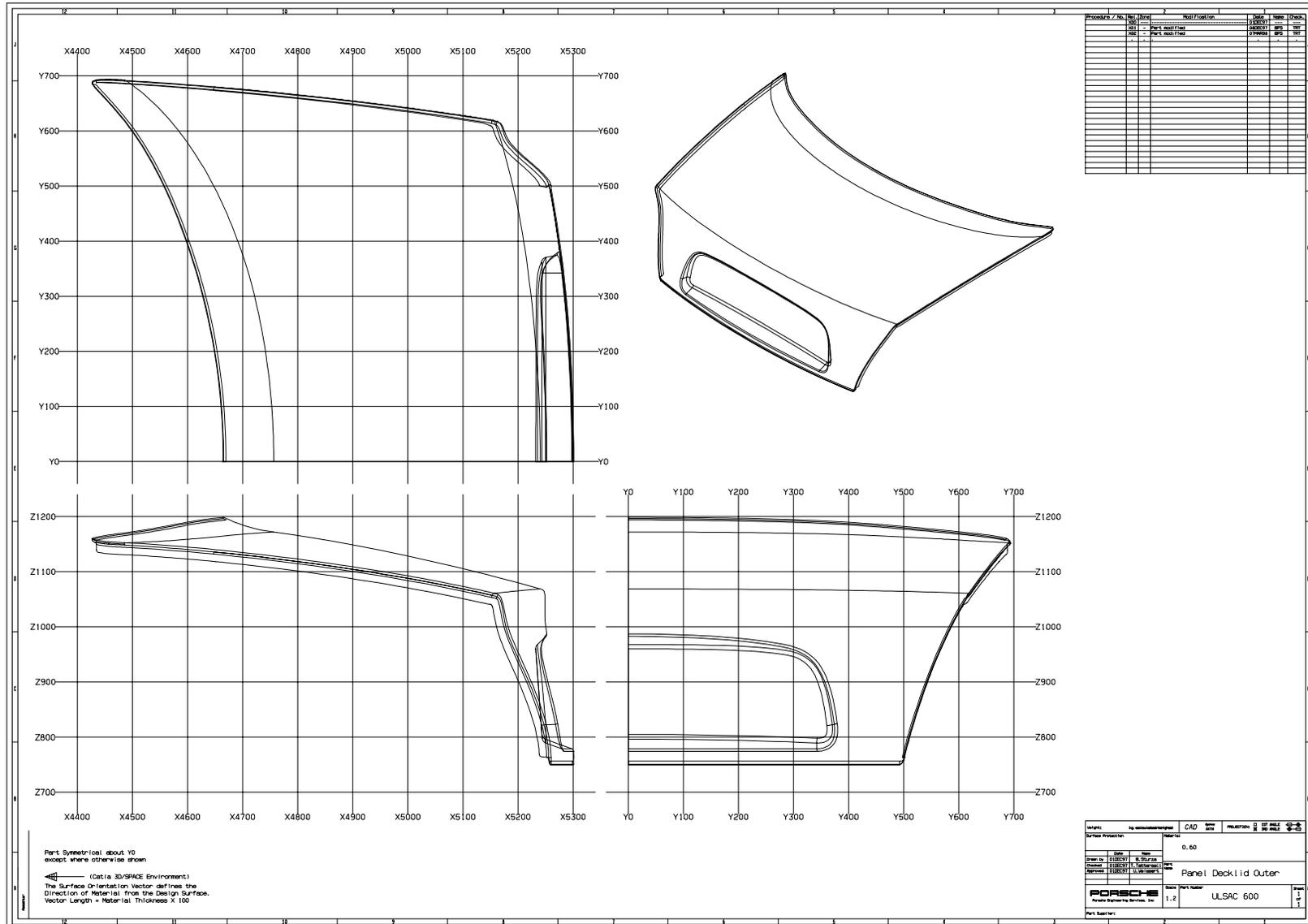






# Part Drawings

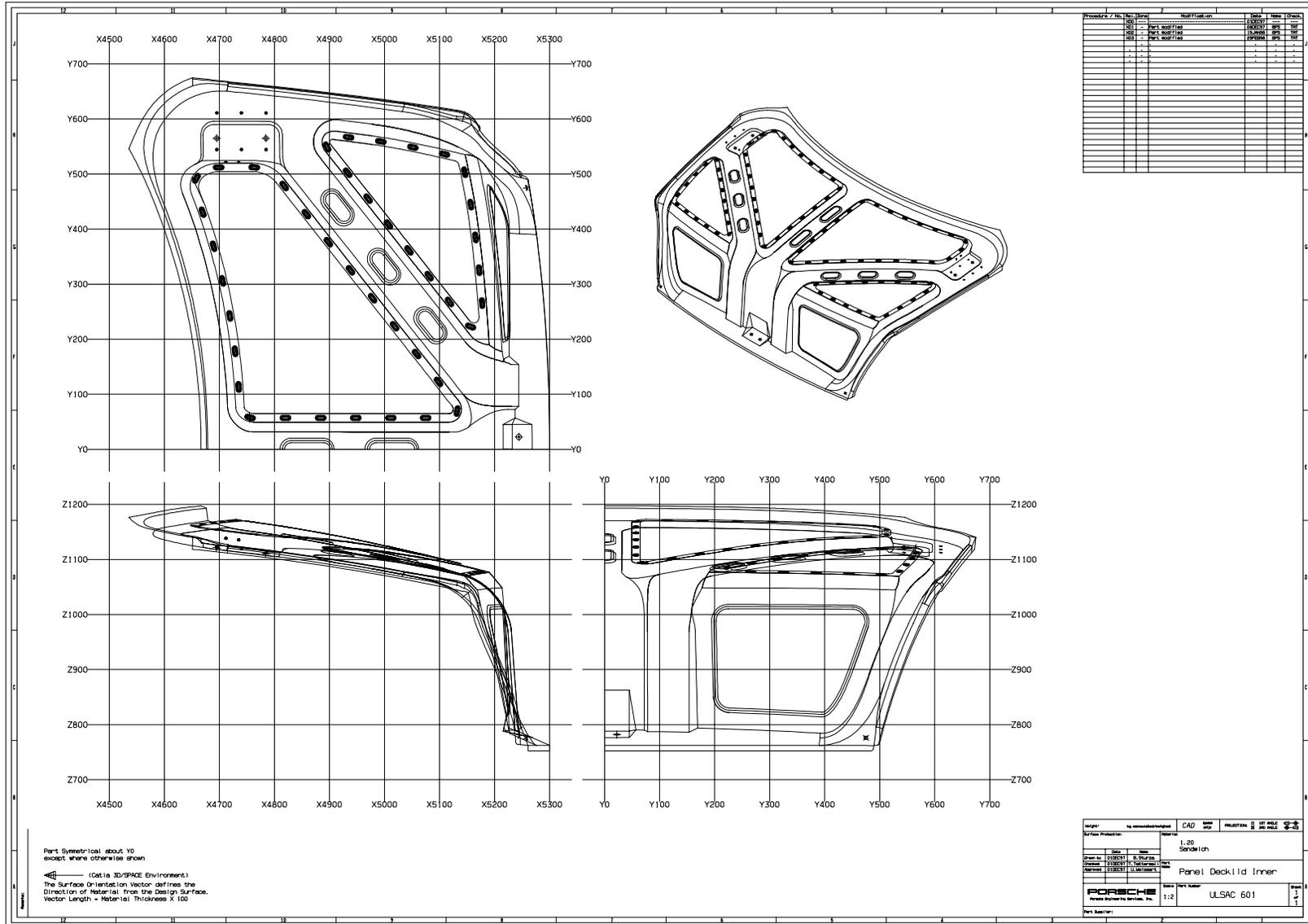
## Part 600 - Panel Decklid Outer





# Part Drawings

## Part 601 - Panel Decklid Inner





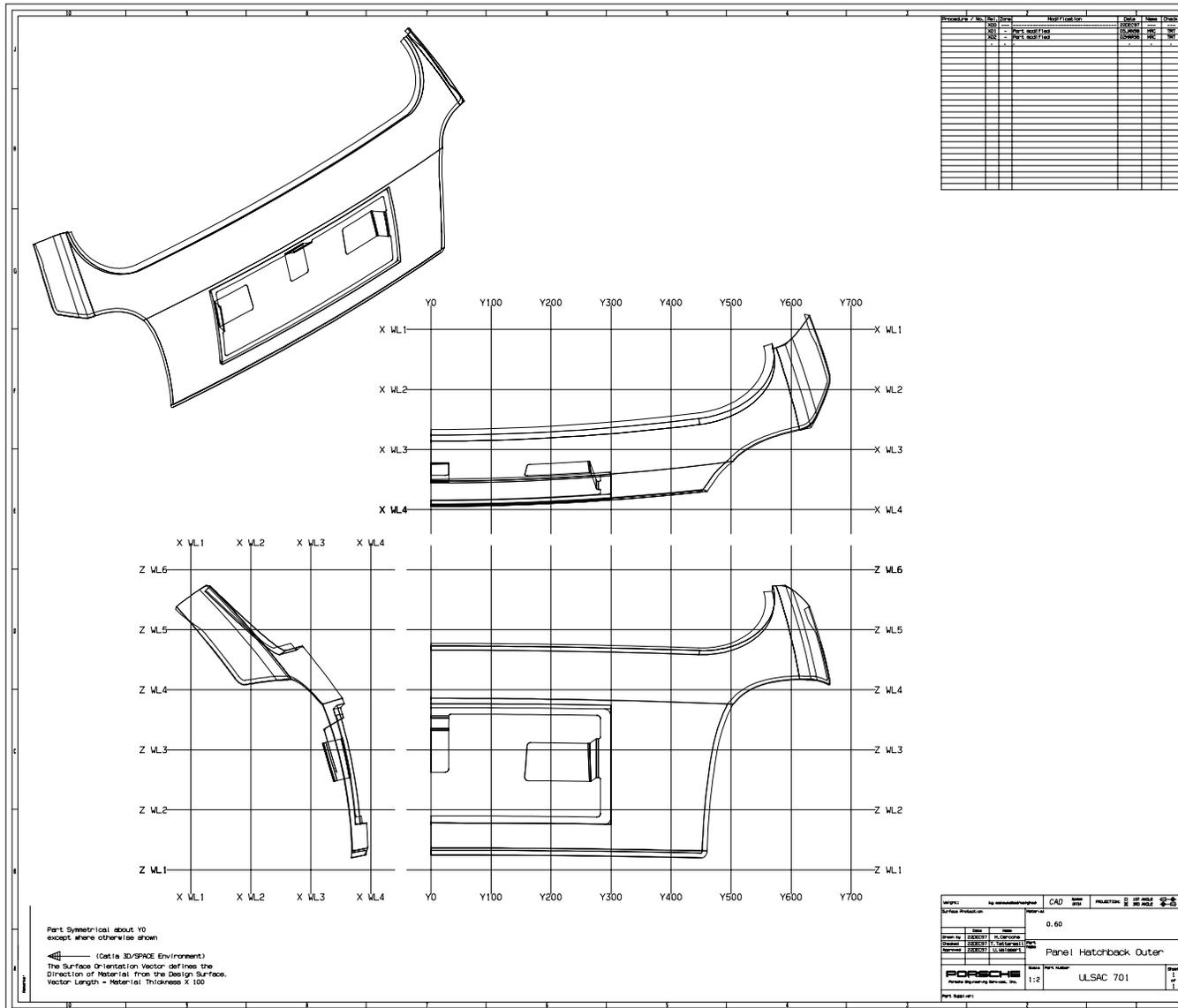






# Part Drawings

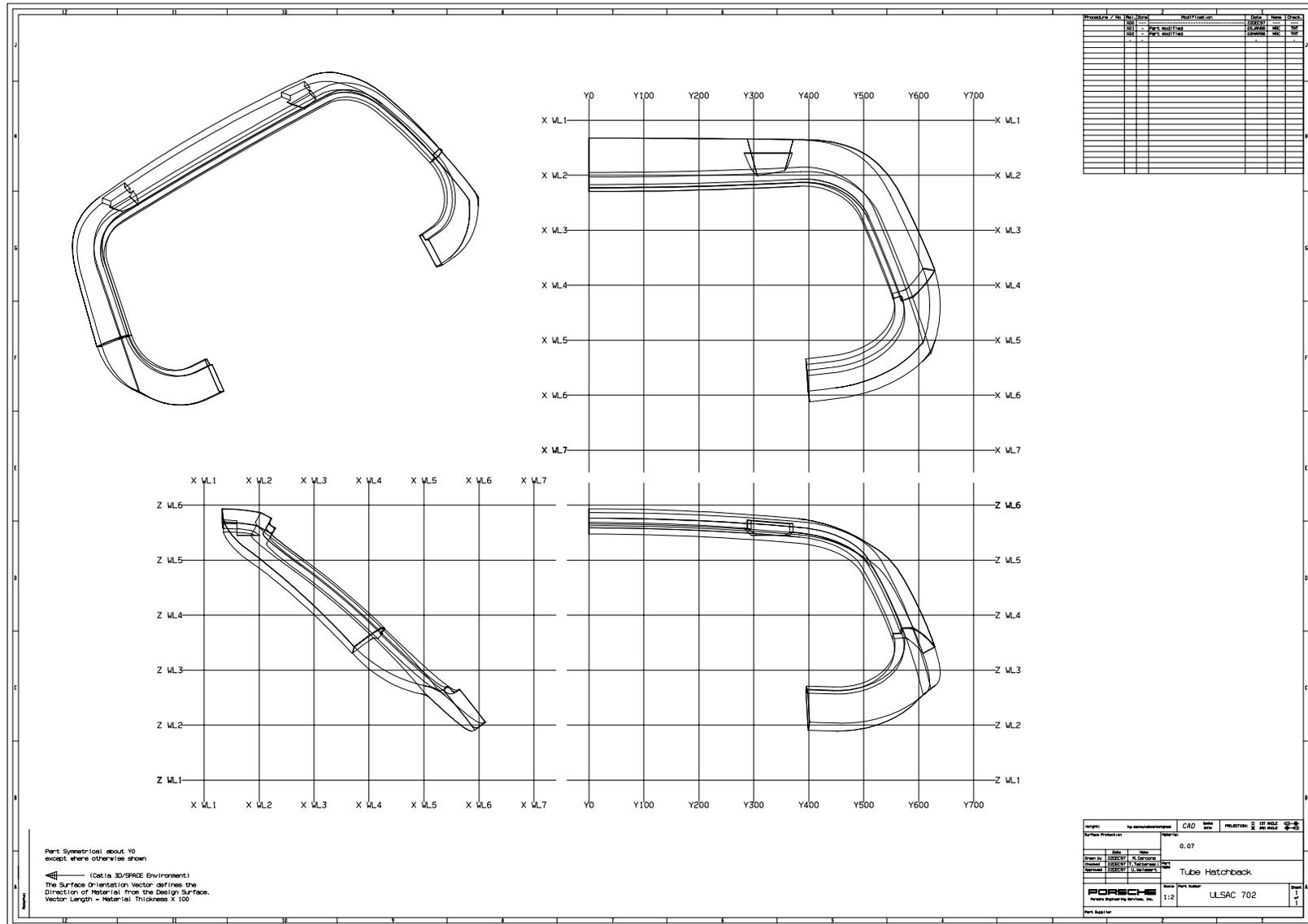
## Part 701 - Panel Hatchback Outer





# Part Drawings

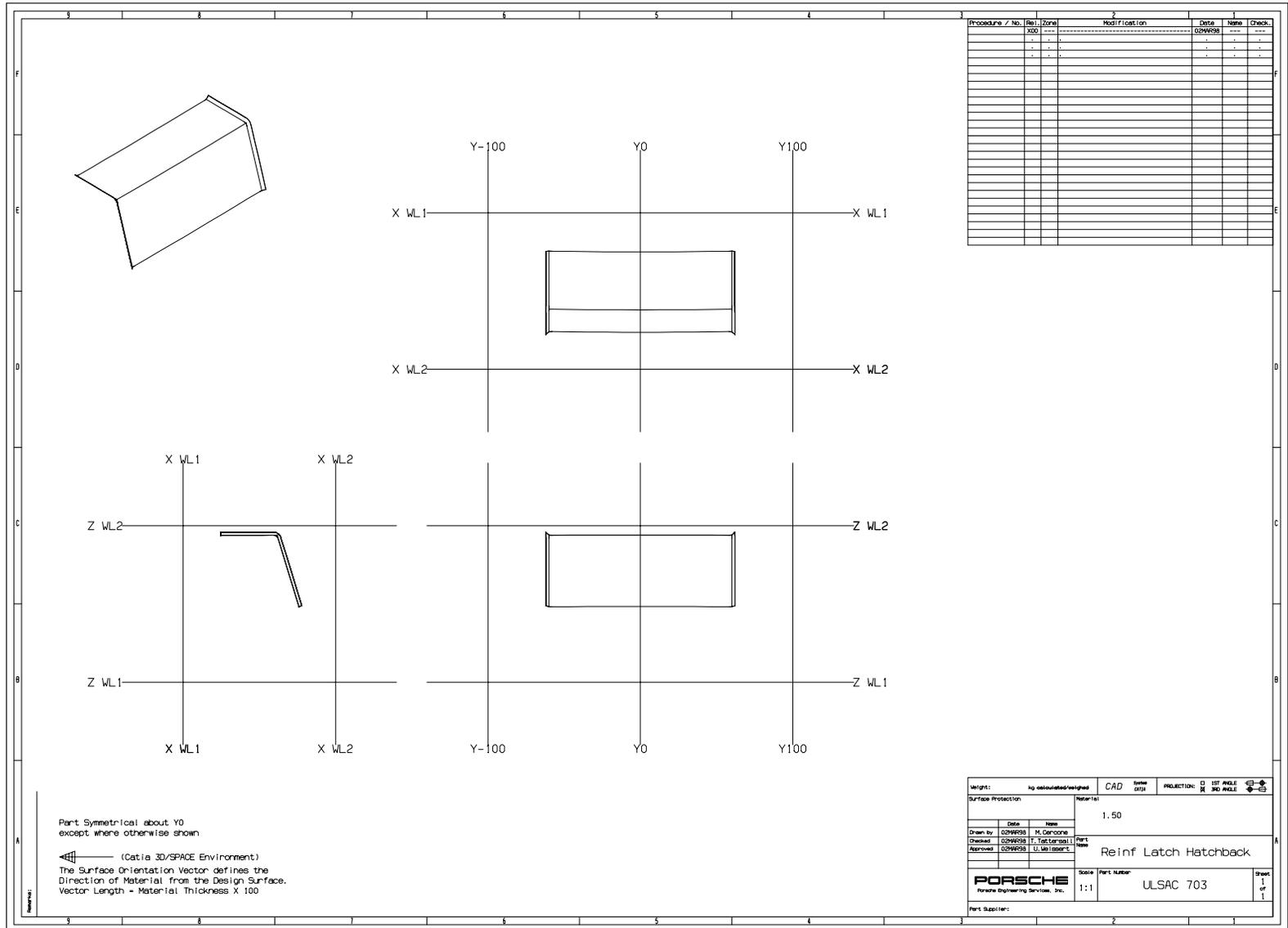
## Part 702 - Tube Hatchback





# Part Drawings

## Part 703 - Reinforcement Latch Hatchback

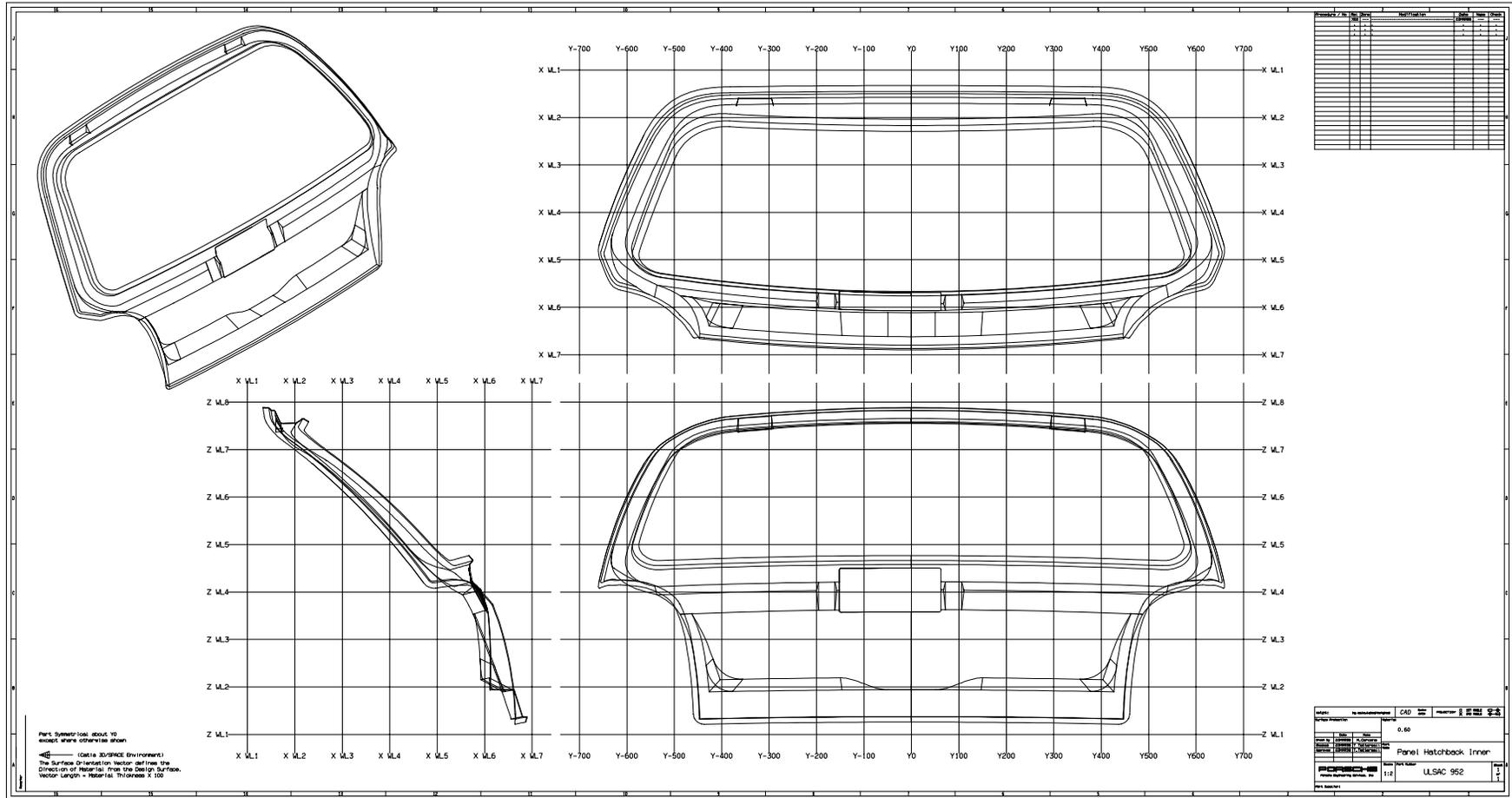






# Part Drawings

## Part 952 - Panel Hatchback Inner - Sheet Hydroformed

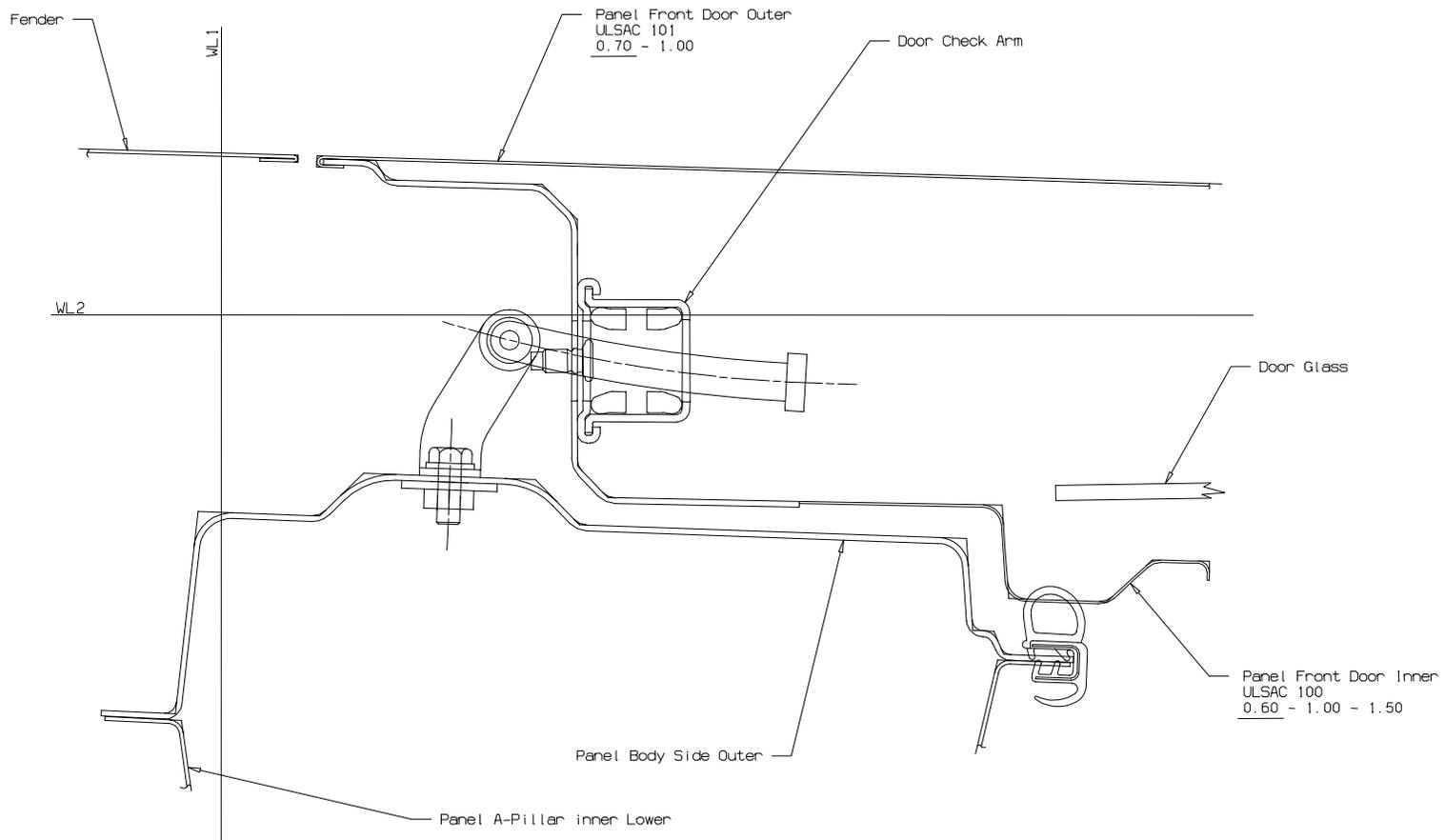




# Conceptual Design

## *Selected Design Concepts - Doors Roof Integrated - Typical Sections*

### Section A1

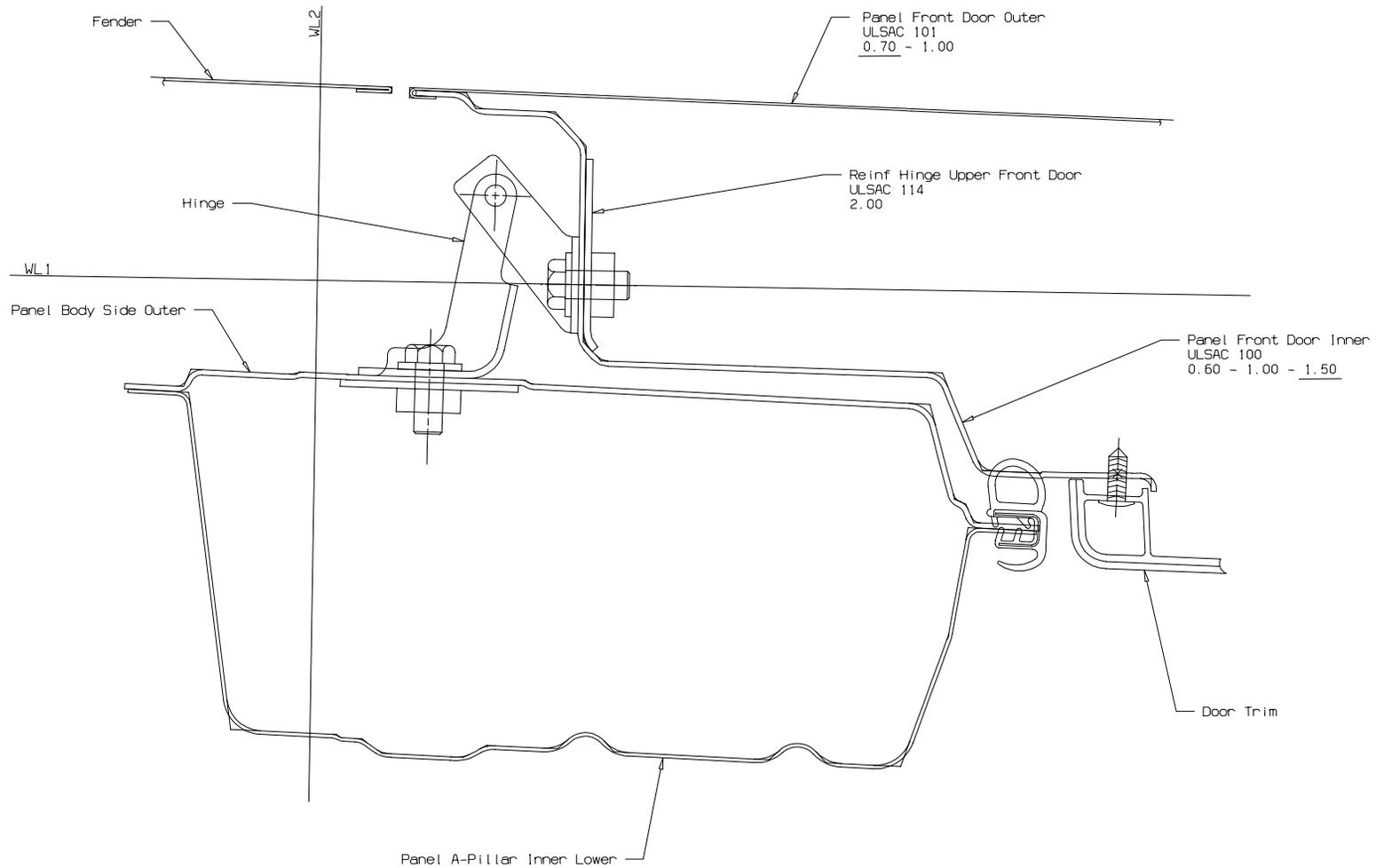




# Conceptual Design

## ***Selected Design Concepts - Doors Roof Integrated - Typical Sections***

### **Section B1**

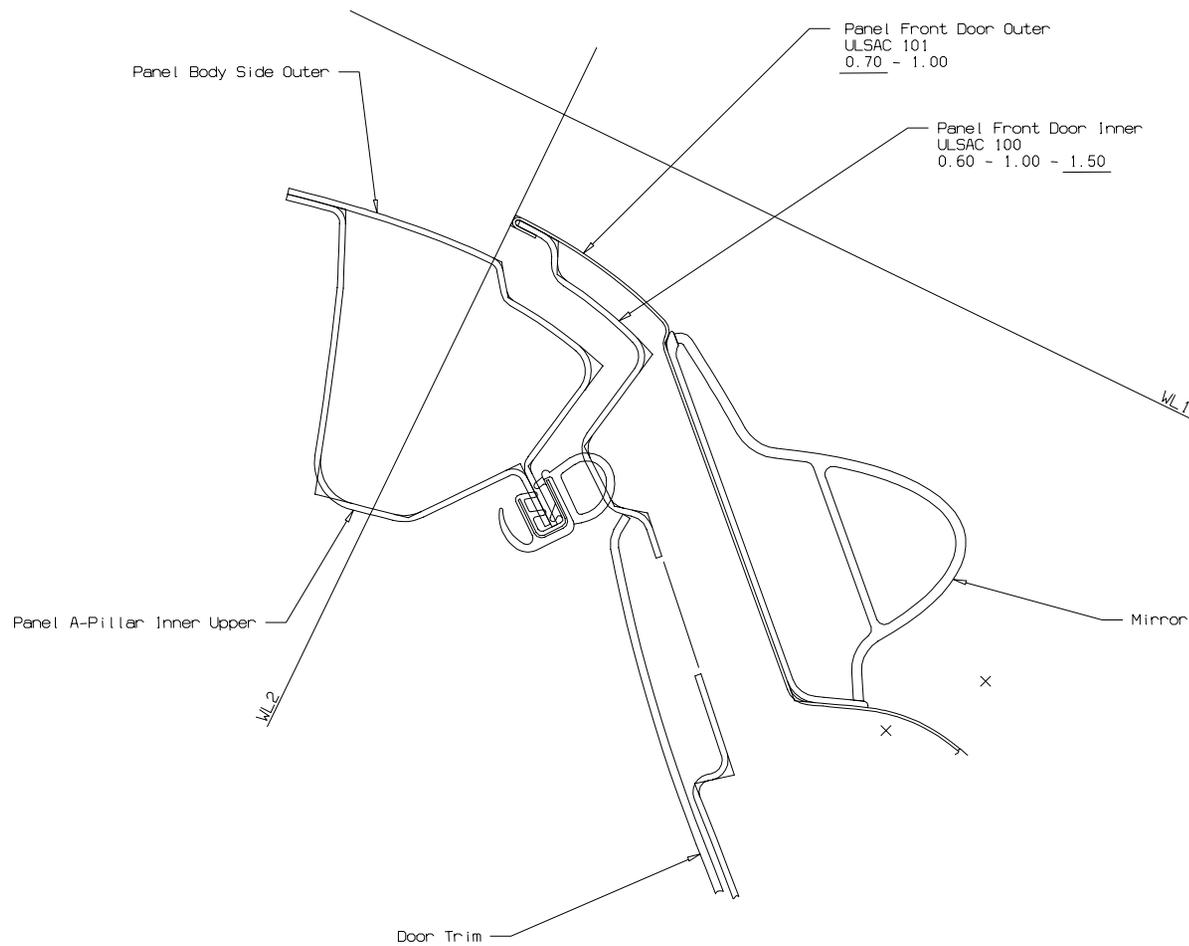




# Conceptual Design

## **Selected Design Concepts - Doors Roof Integrated - Typical Sections**

### **Section C1**

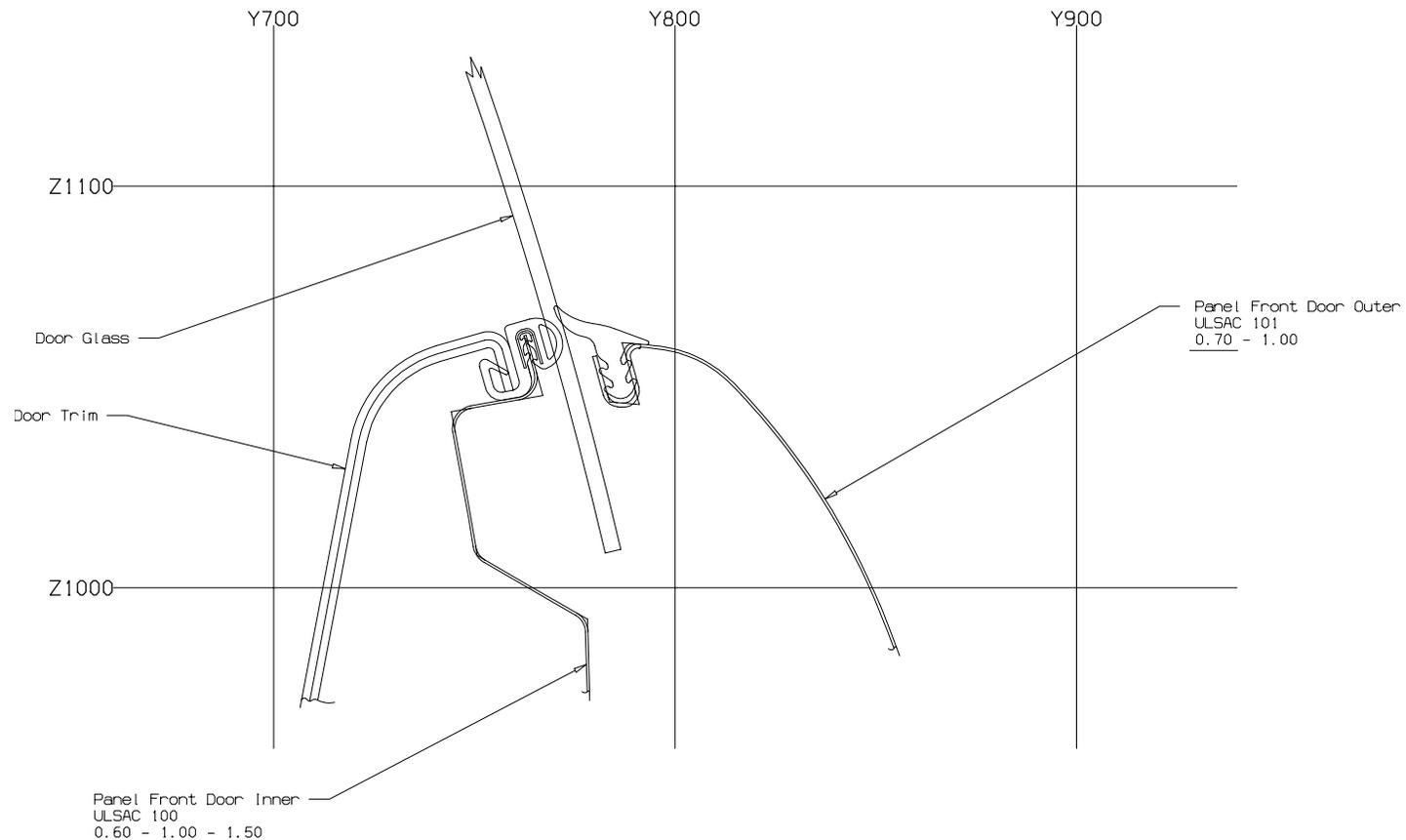




# Conceptual Design

## ***Selected Design Concepts - Doors Roof Integrated - Typical Sections***

### **Section D1**

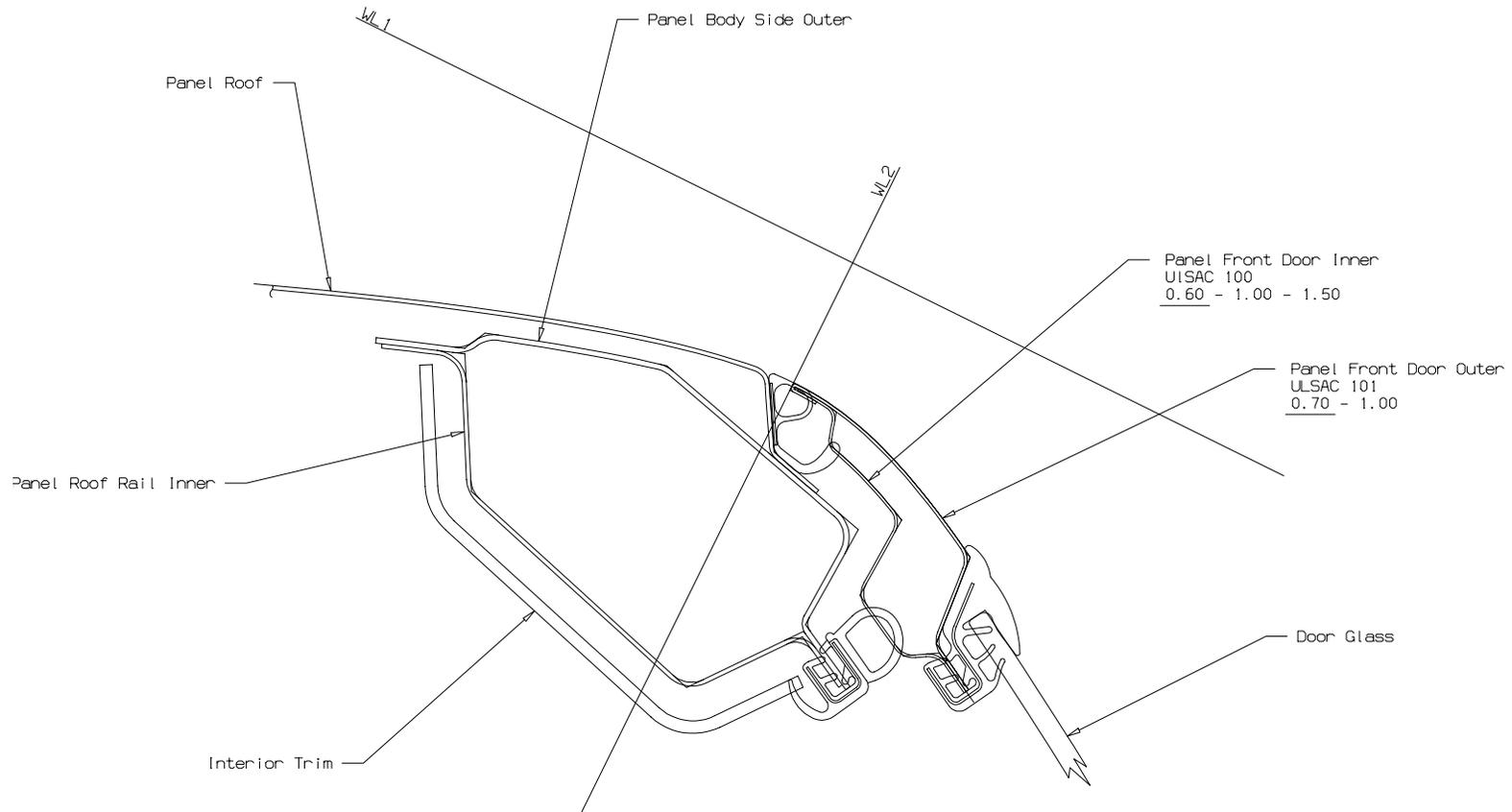




# Conceptual Design

## **Selected Design Concepts - Doors Roof Integrated - Typical Sections**

### **Section E1**

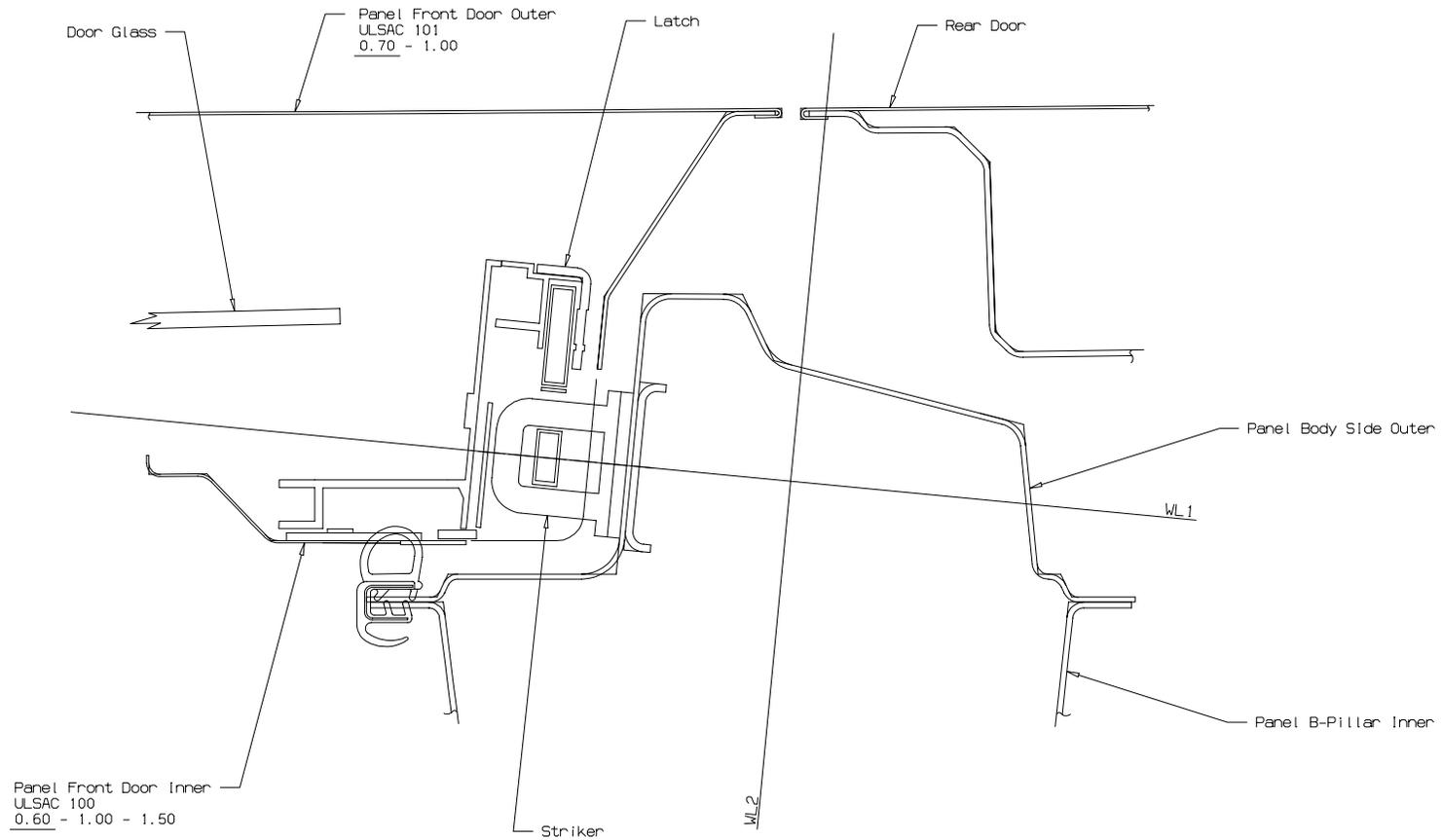




# Conceptual Design

## ***Selected Design Concepts - Doors Roof Integrated - Typical Sections***

### **Section F1**

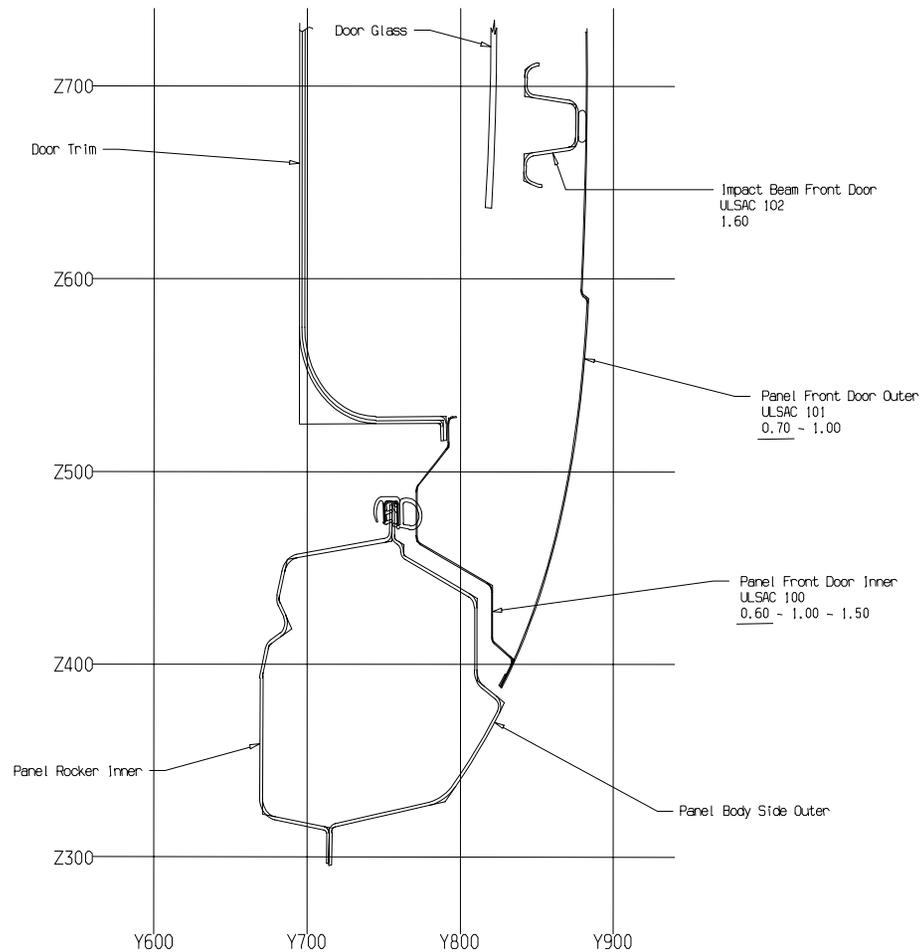




# Conceptual Design

## ***Selected Design Concepts - Doors Roof Integrated - Typical Sections***

### **Section G1**

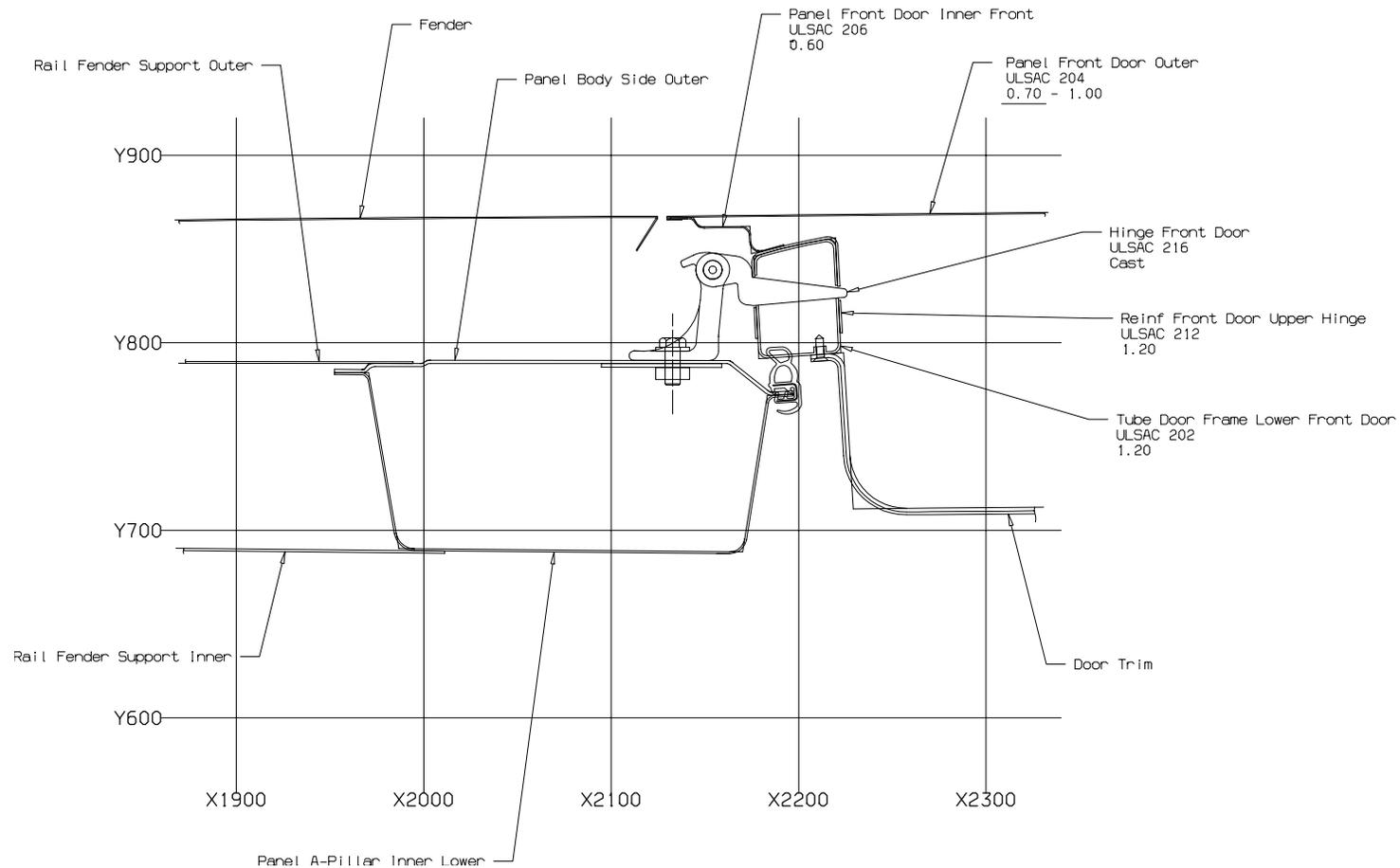




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section A2**

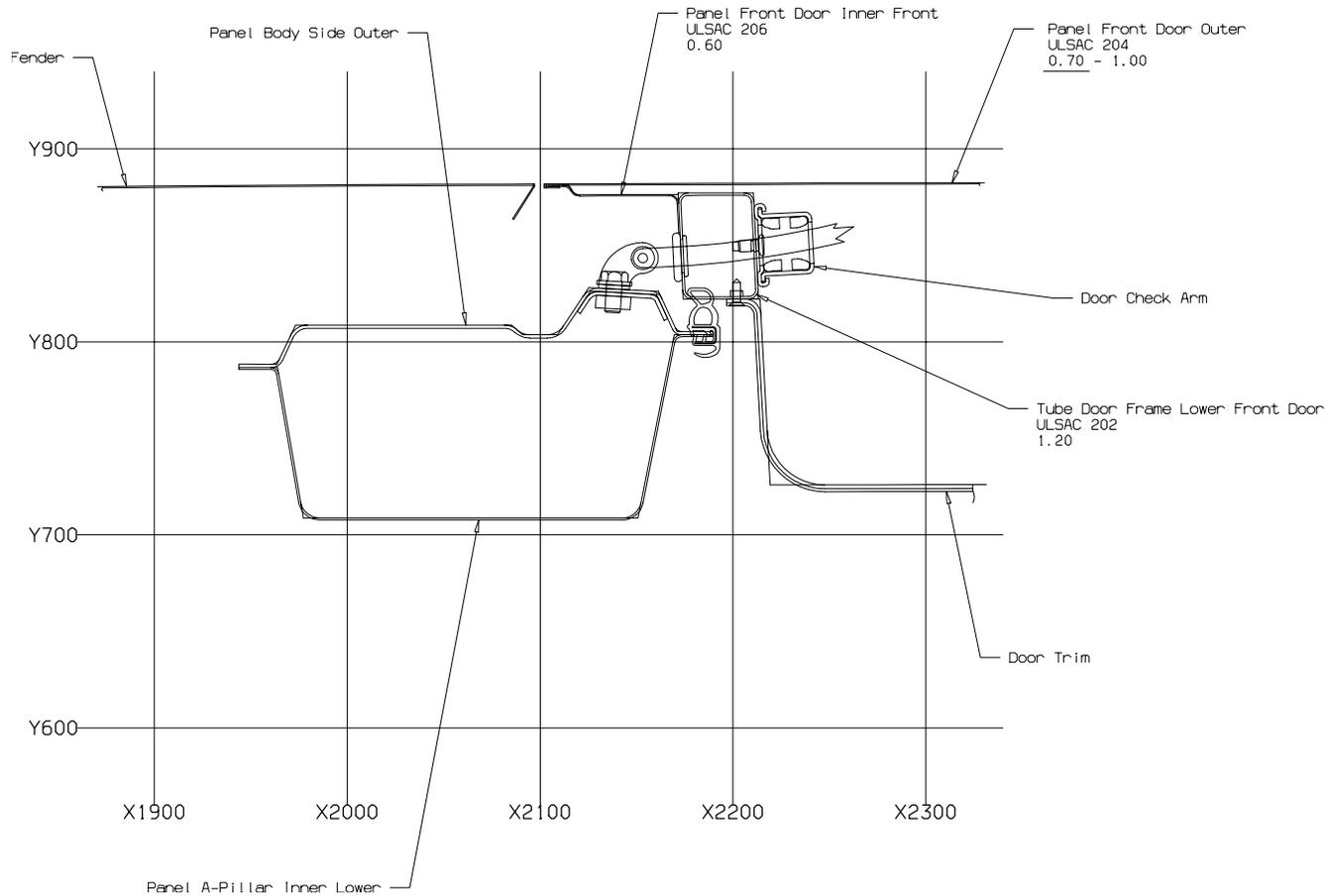




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section B2**

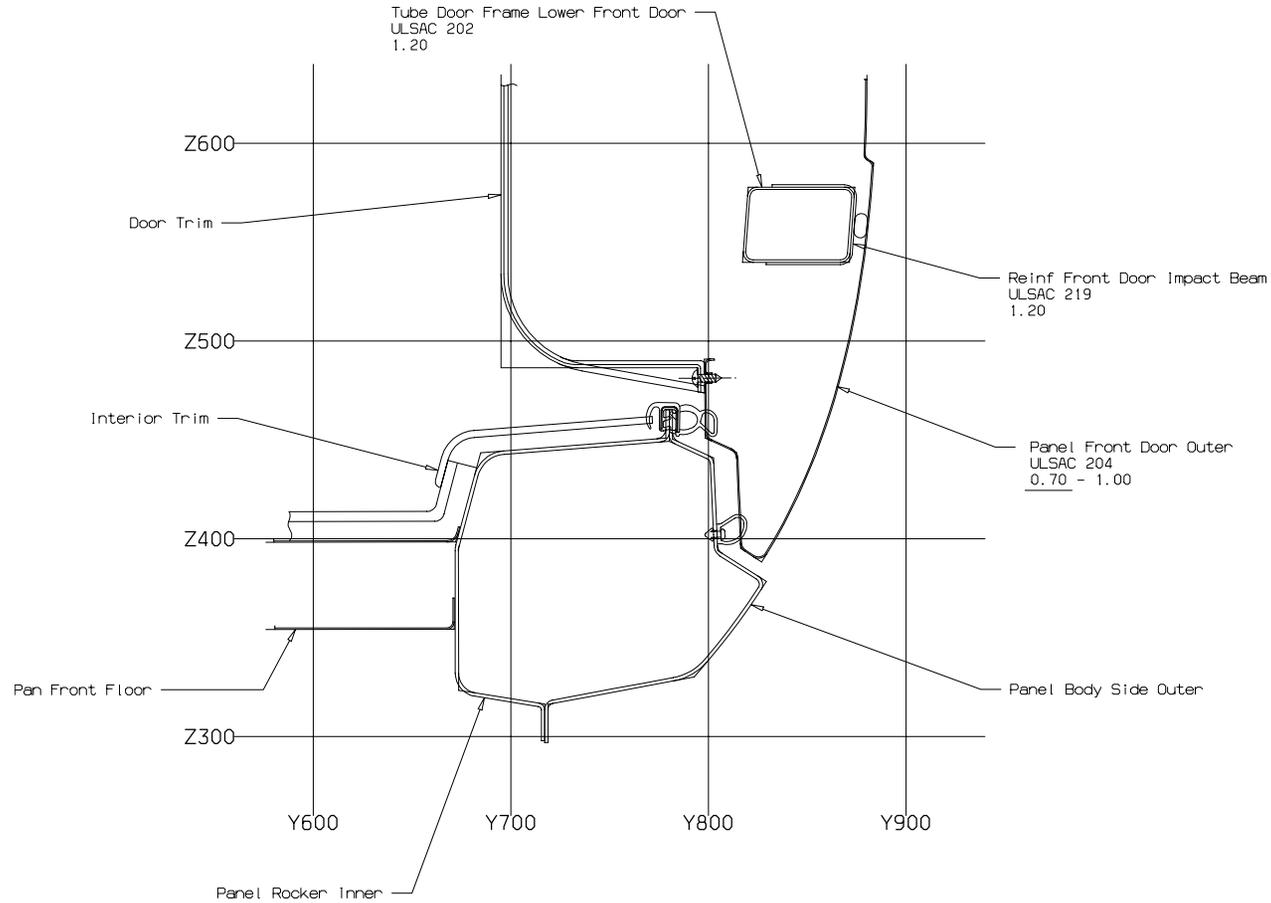




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section C2**

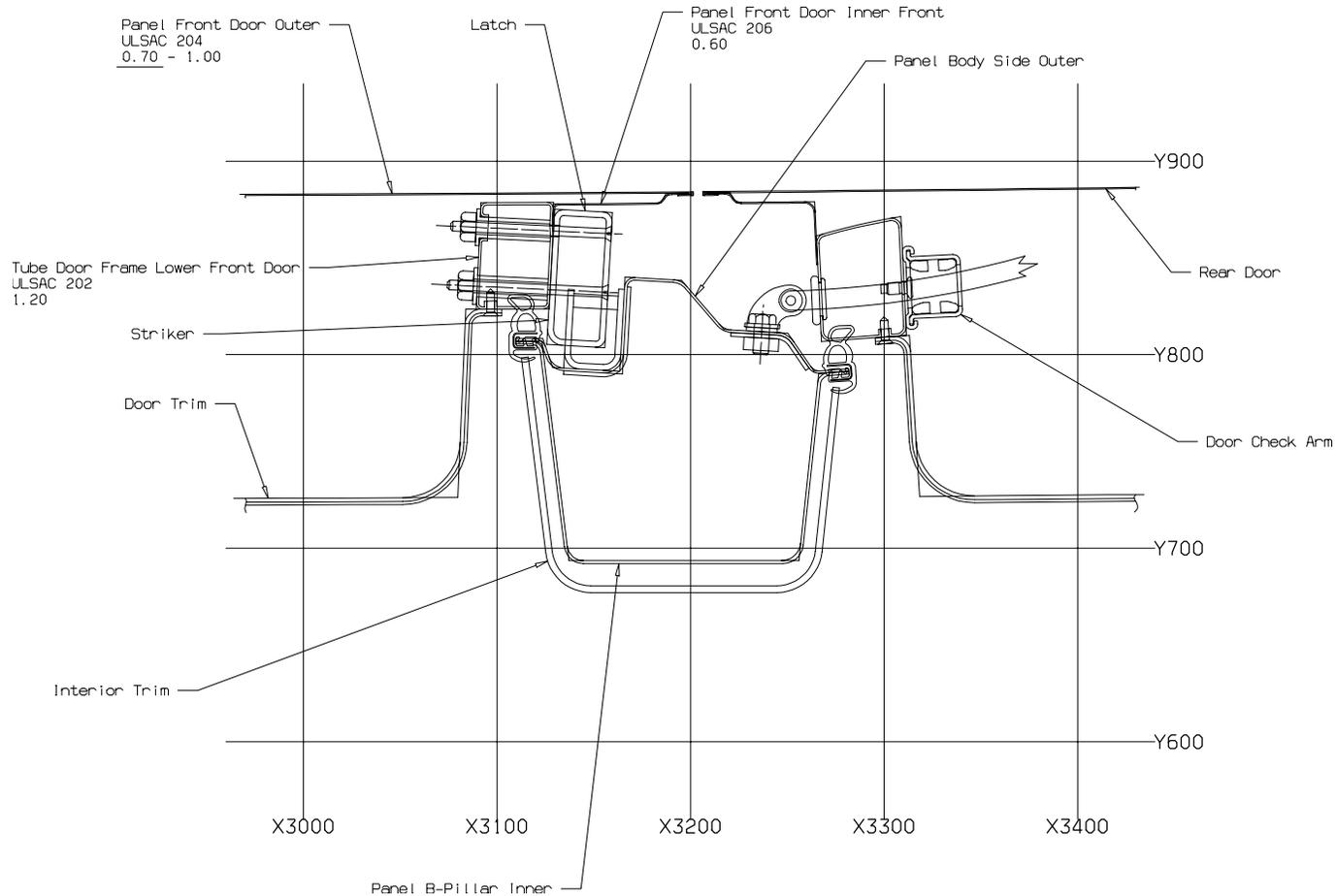




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section D2**

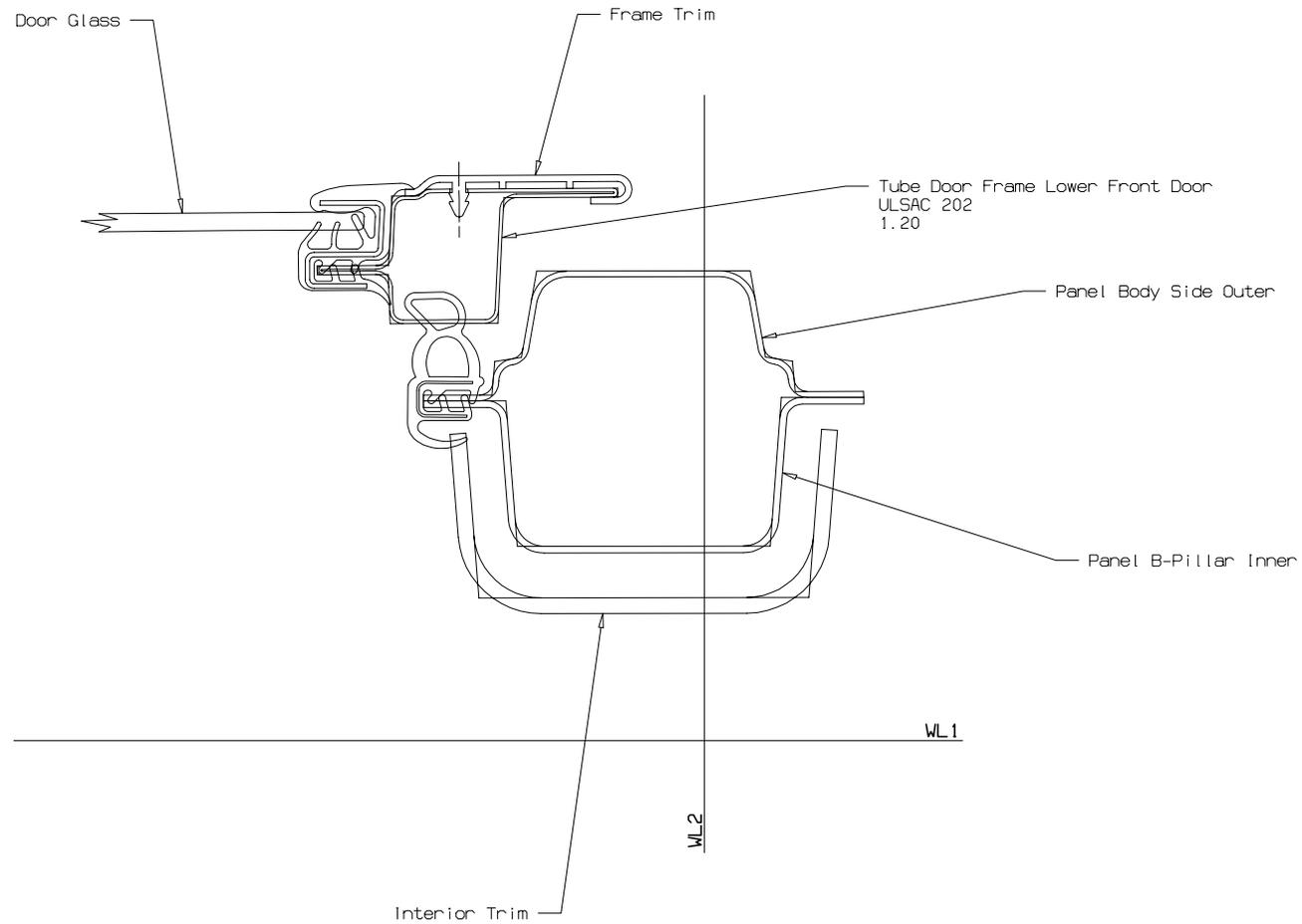




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section E2**

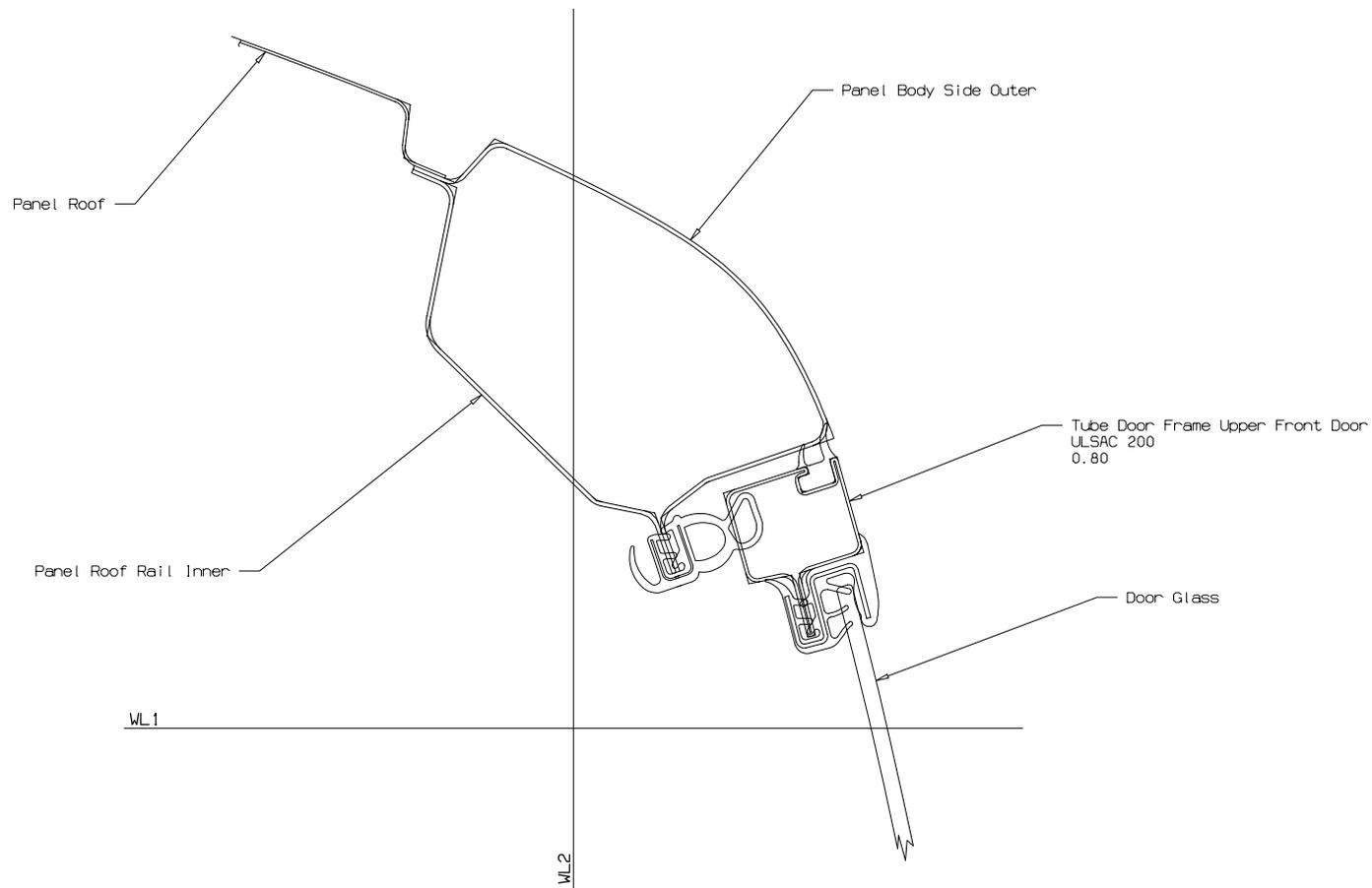




# Conceptual Design

## ***Selected Design Concepts - Doors Frame Integrated - Typical Sections***

### **Section F2**

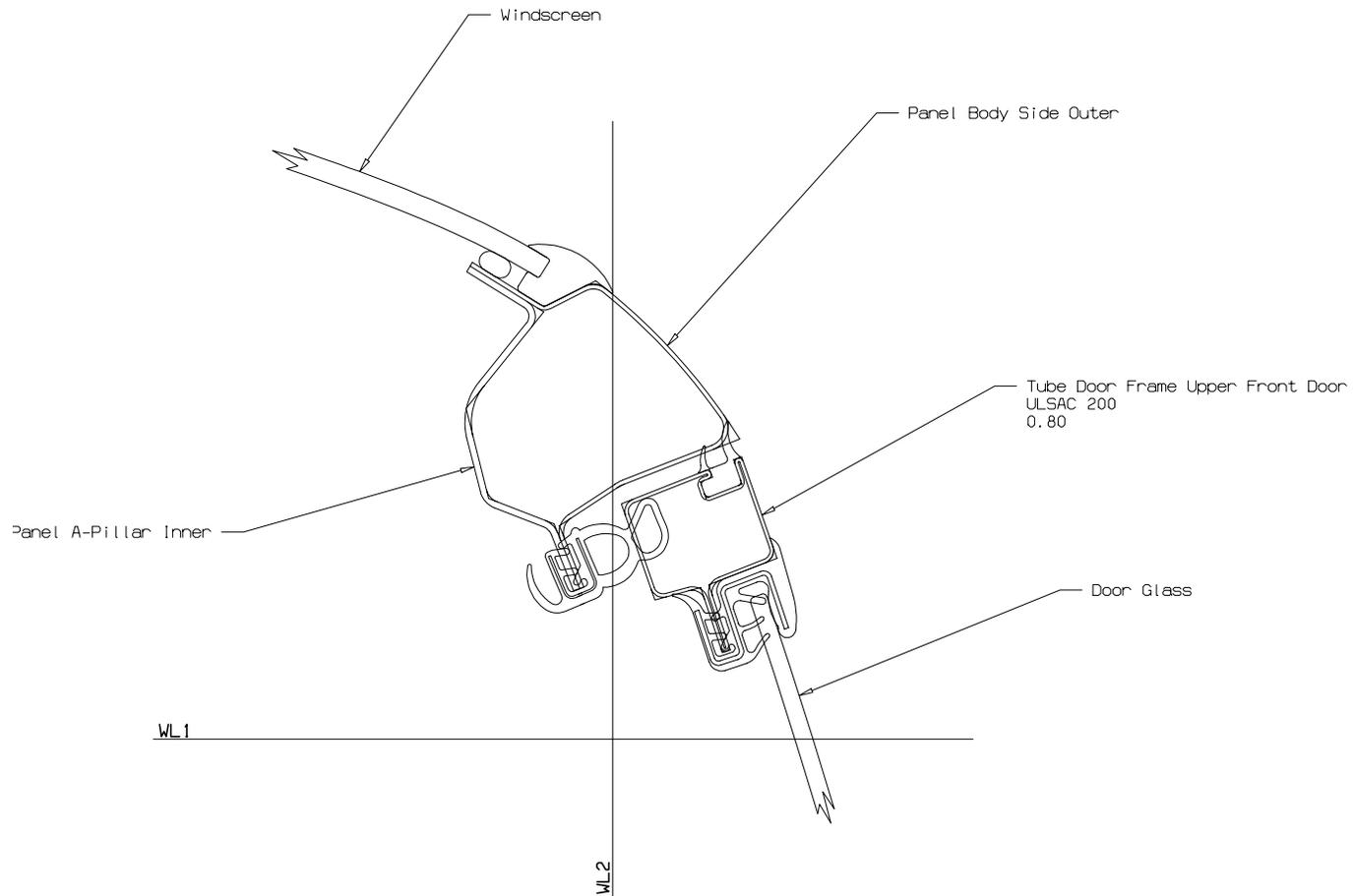




# Conceptual Design

## **Selected Design Concepts - Doors Frame Integrated - Typical Sections**

### **Section G2**

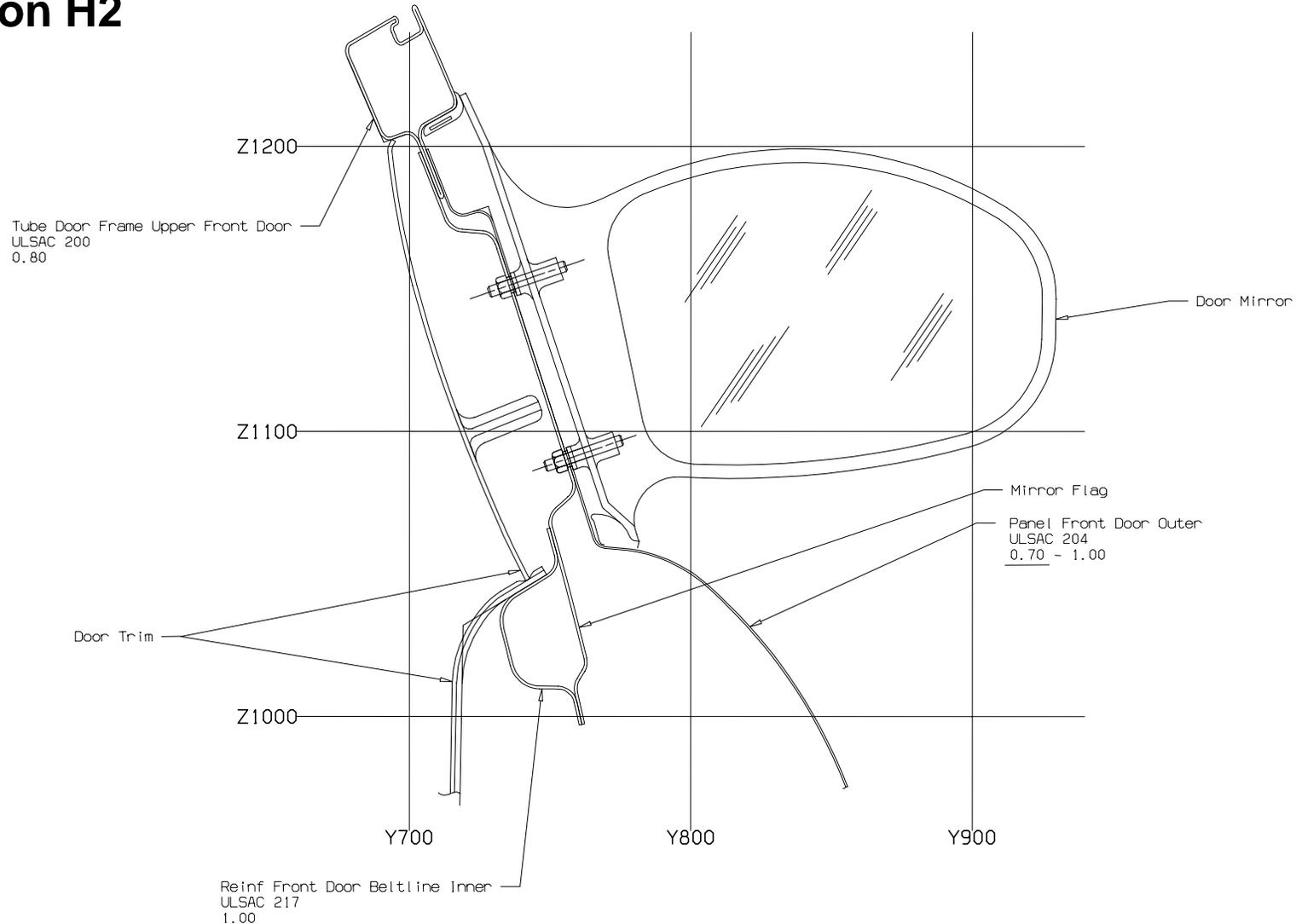




# Conceptual Design

## ***Selected Design Concepts - Doors Frame Integrated - Typical Sections***

### **Section H2**

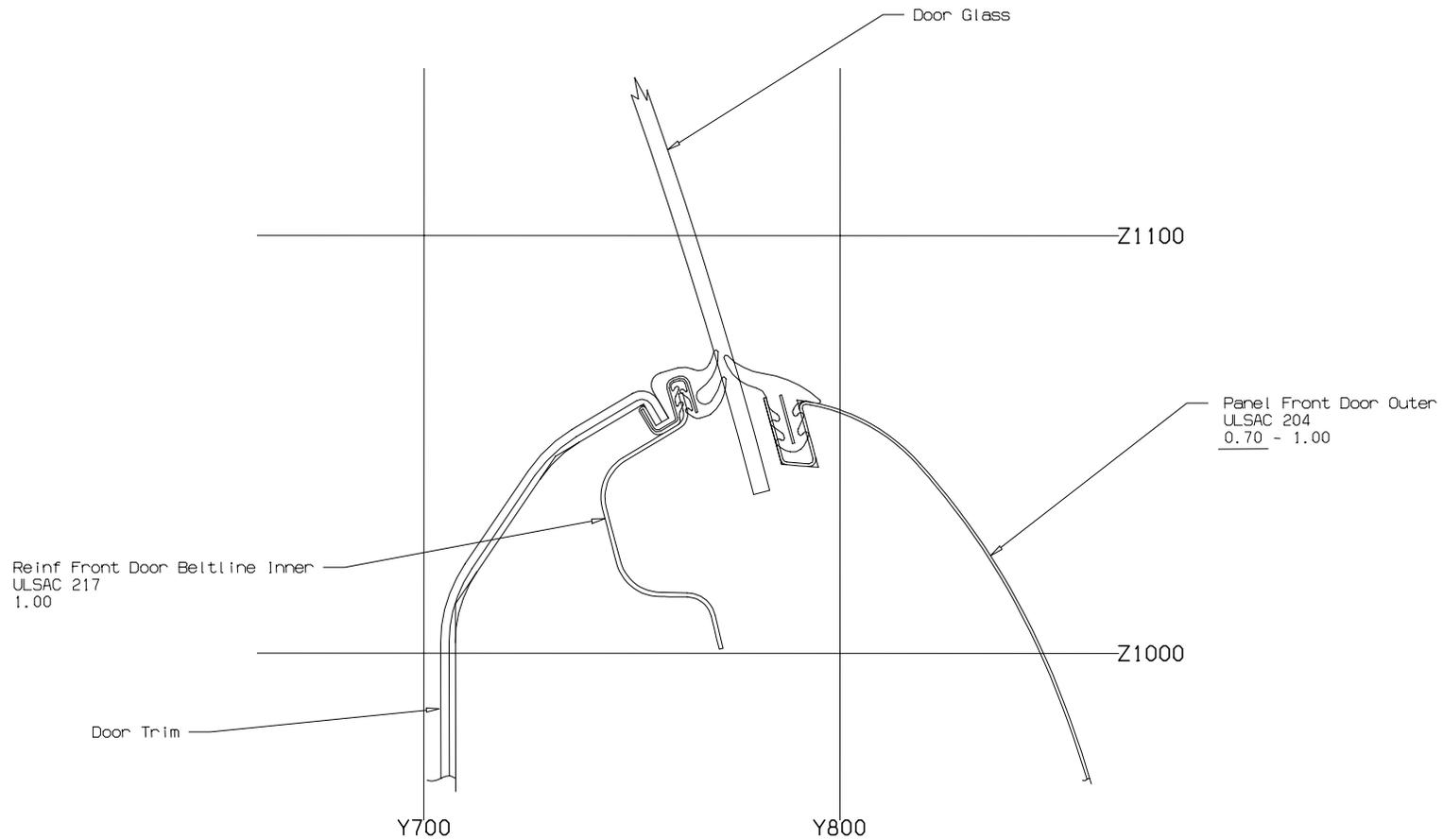




# Conceptual Design

## ***Selected Design Concepts - Doors Frame Integrated - Typical Sections***

### **Section I2**

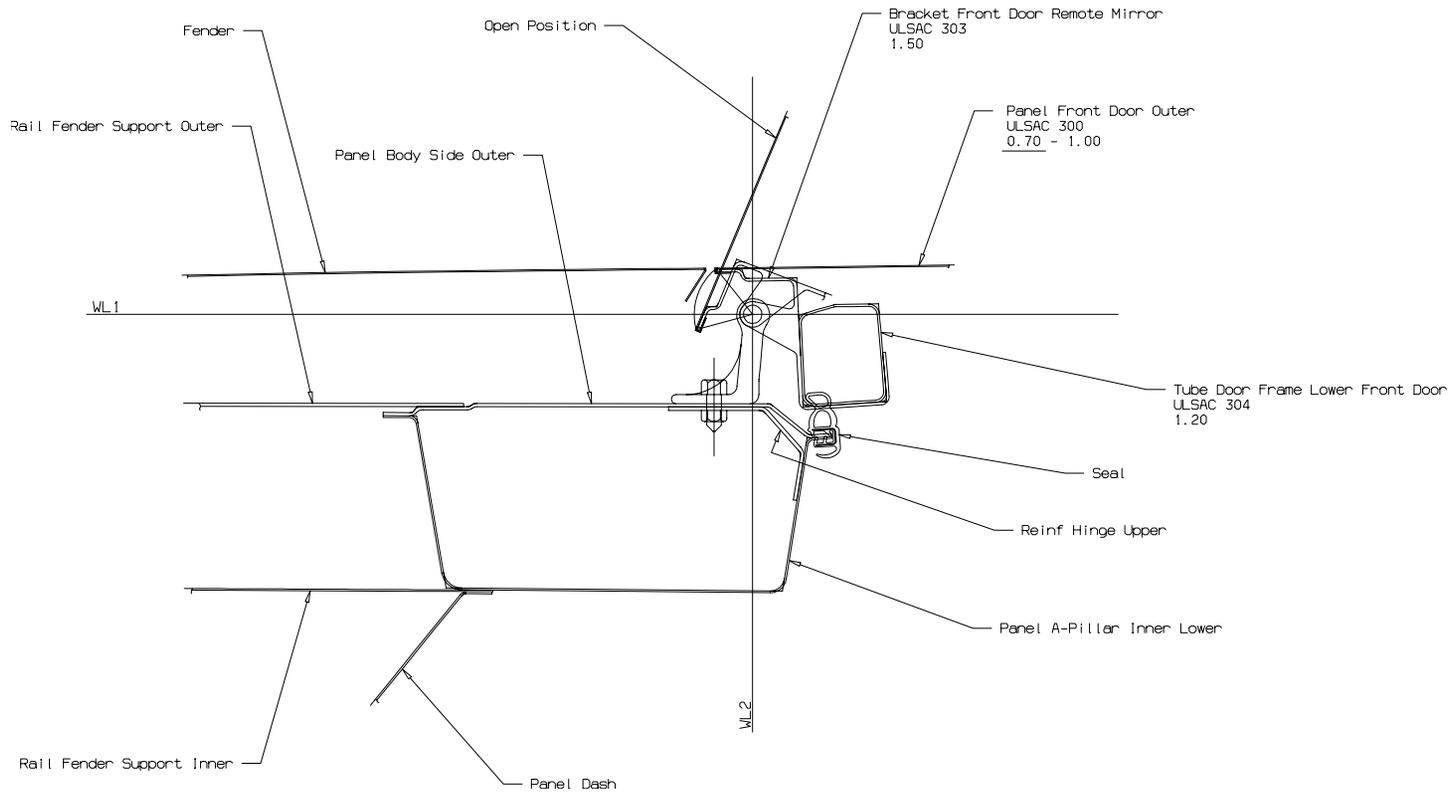




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section A3**

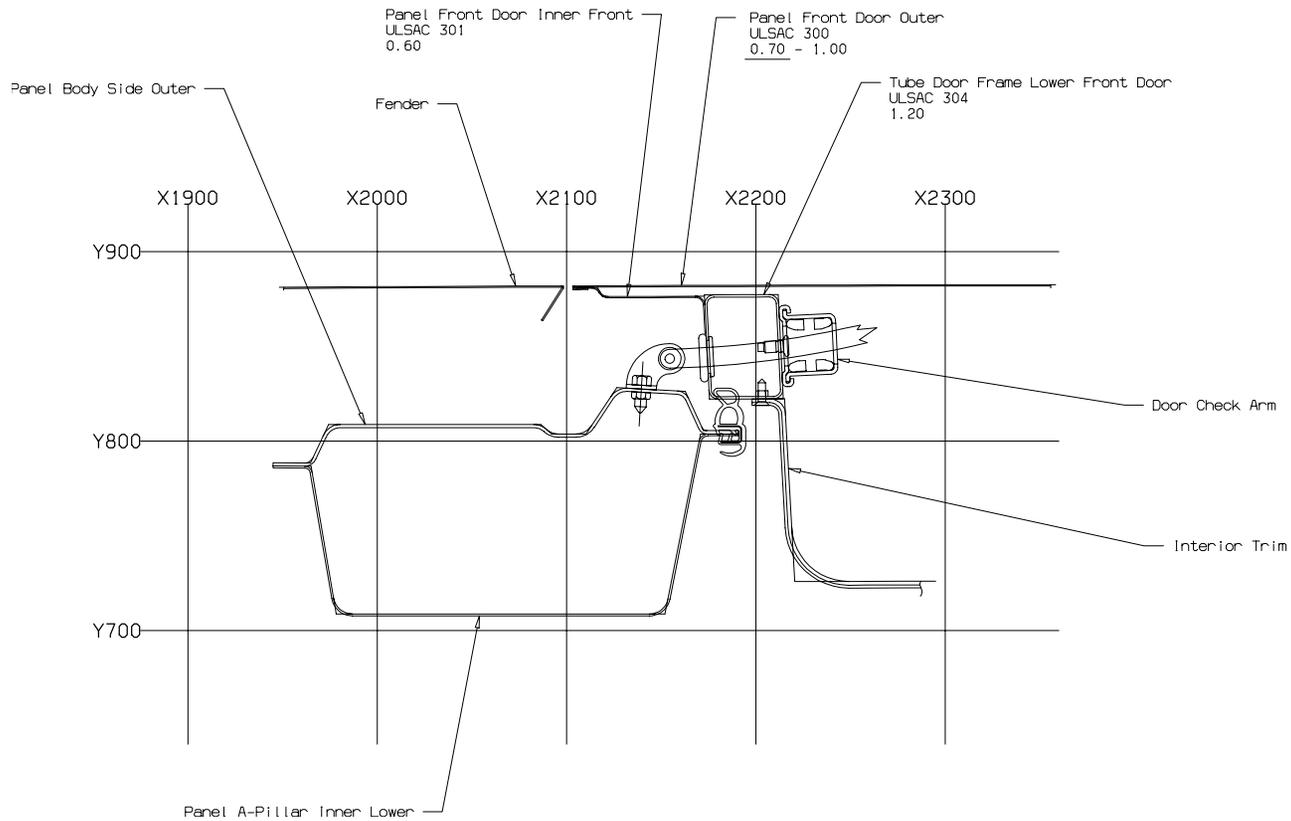




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section B3**

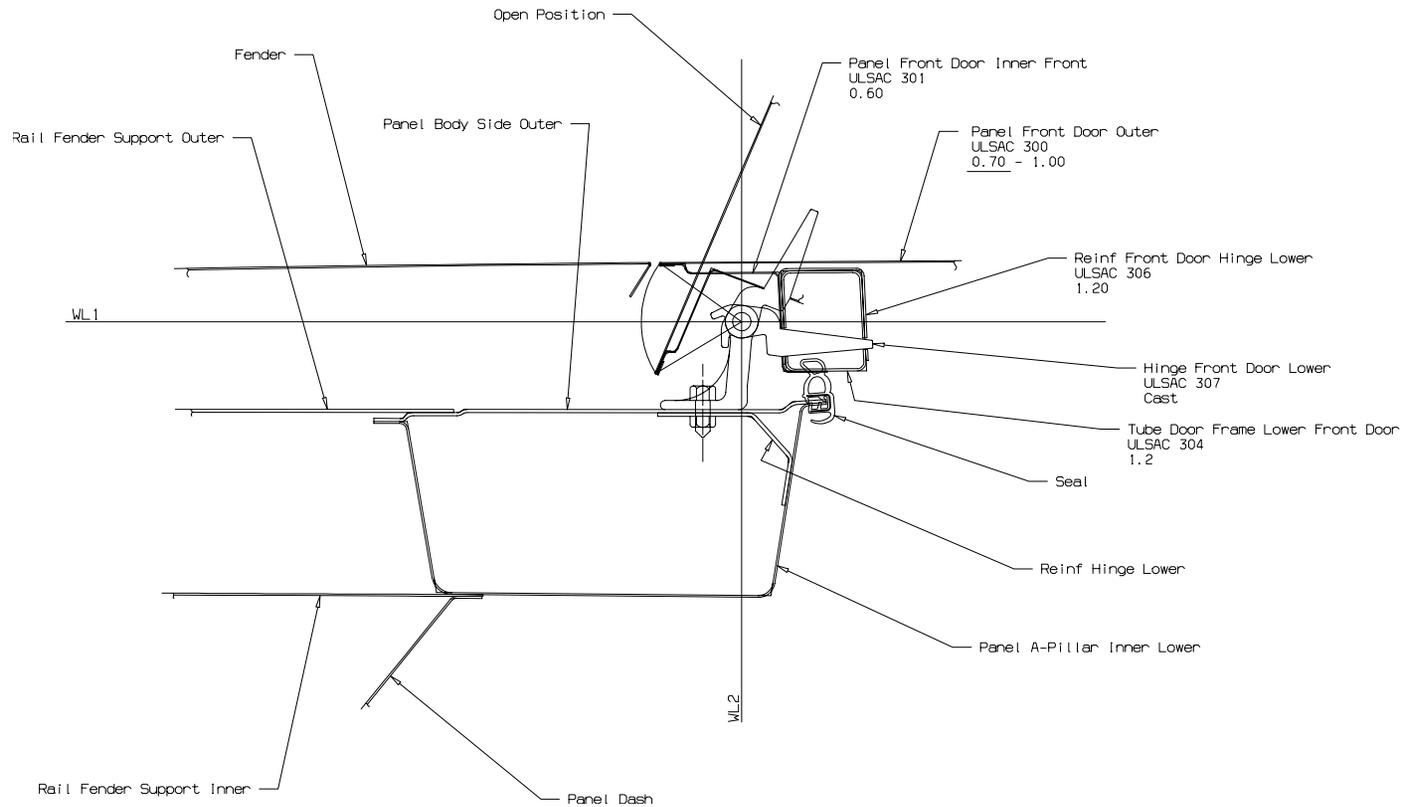




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section C3**

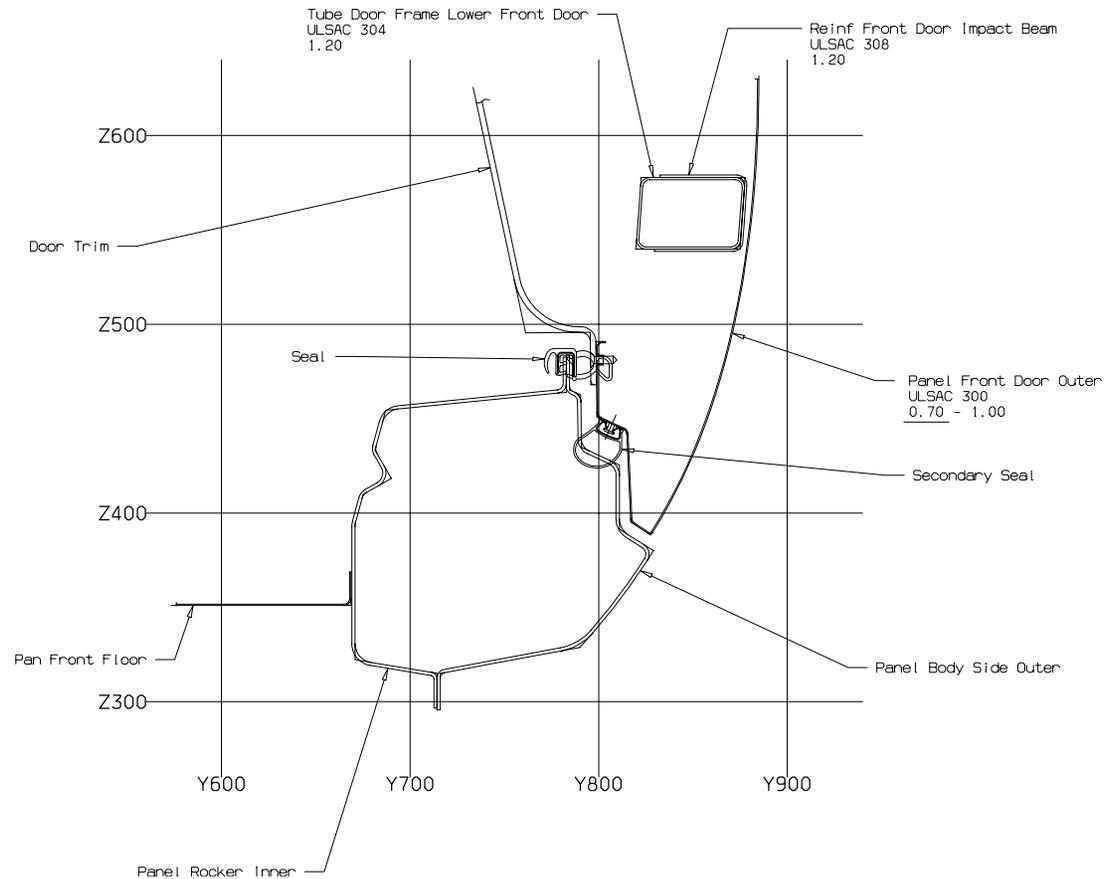




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section D3**

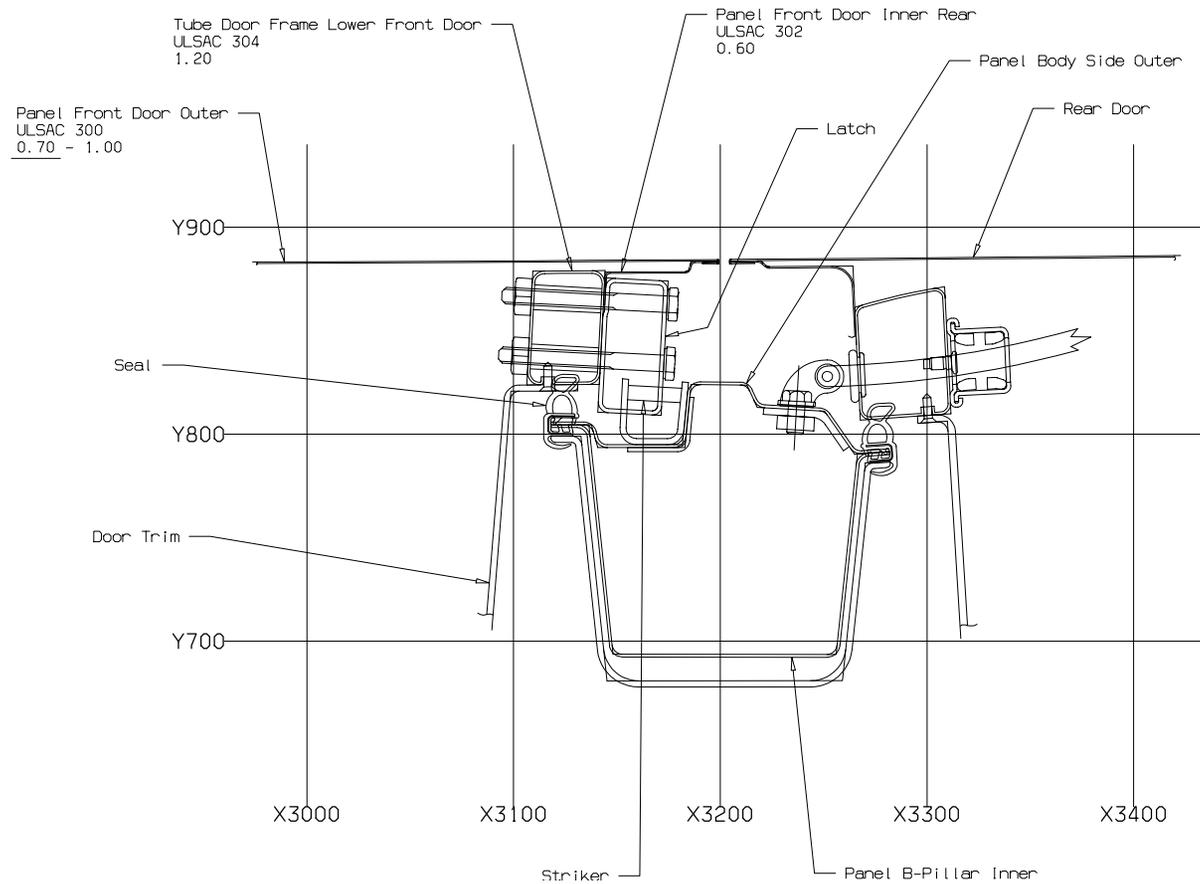




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section E3**

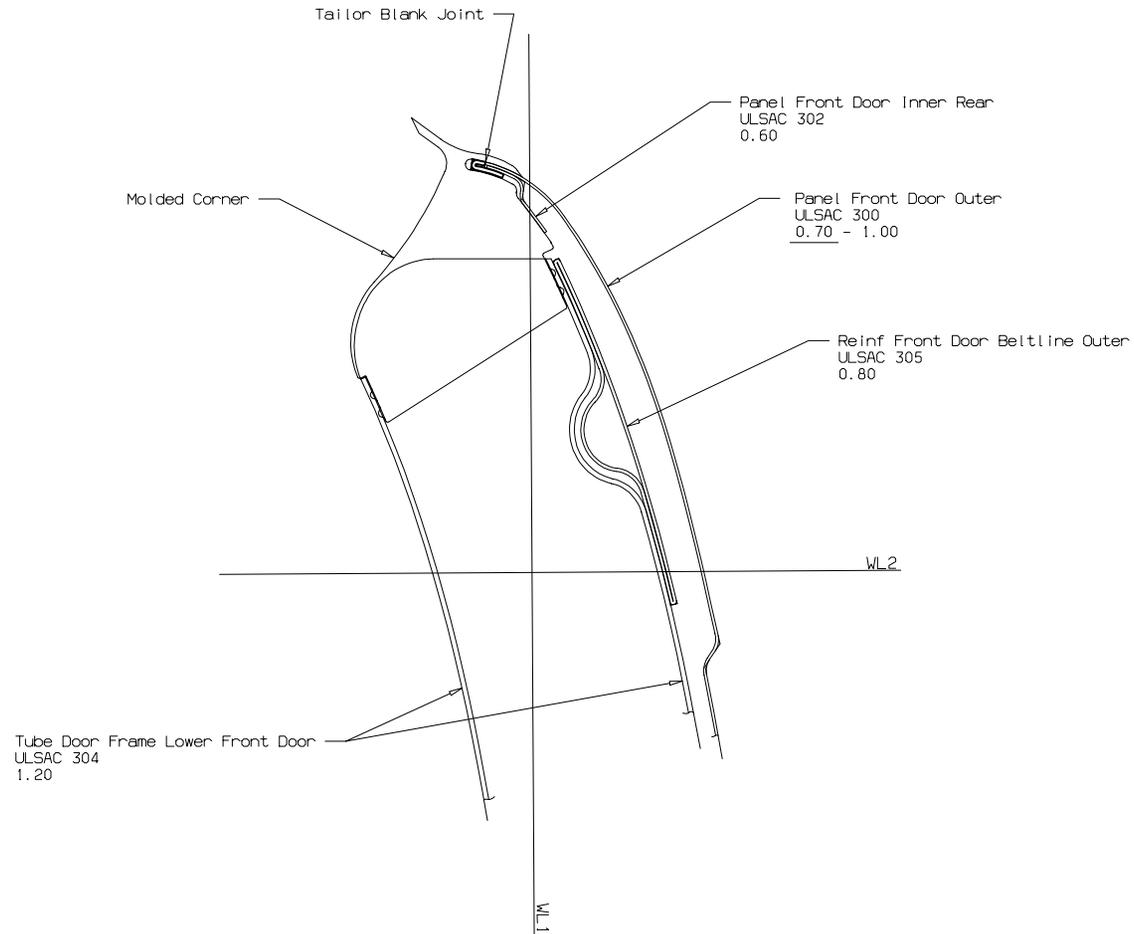




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section F3**

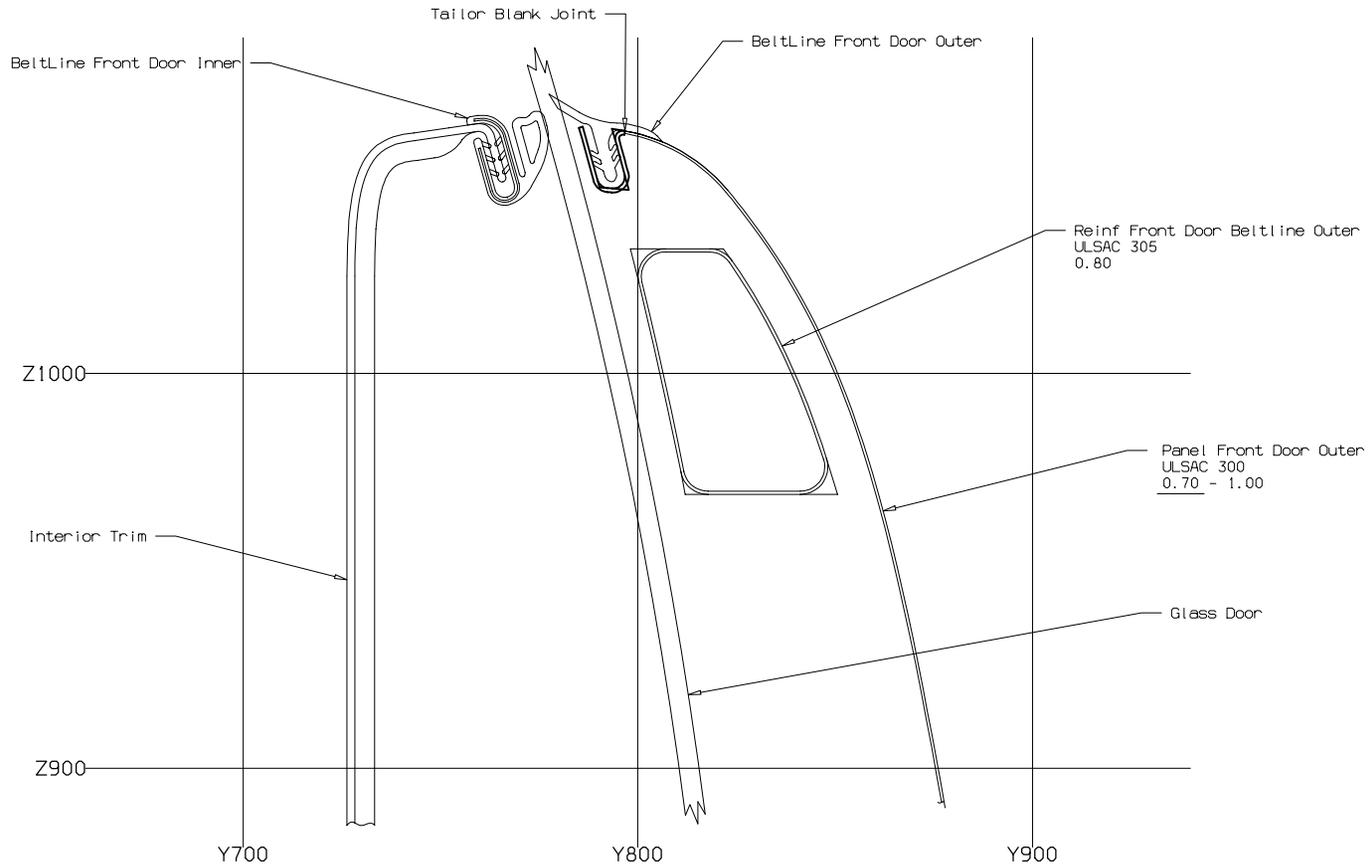




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section G3**

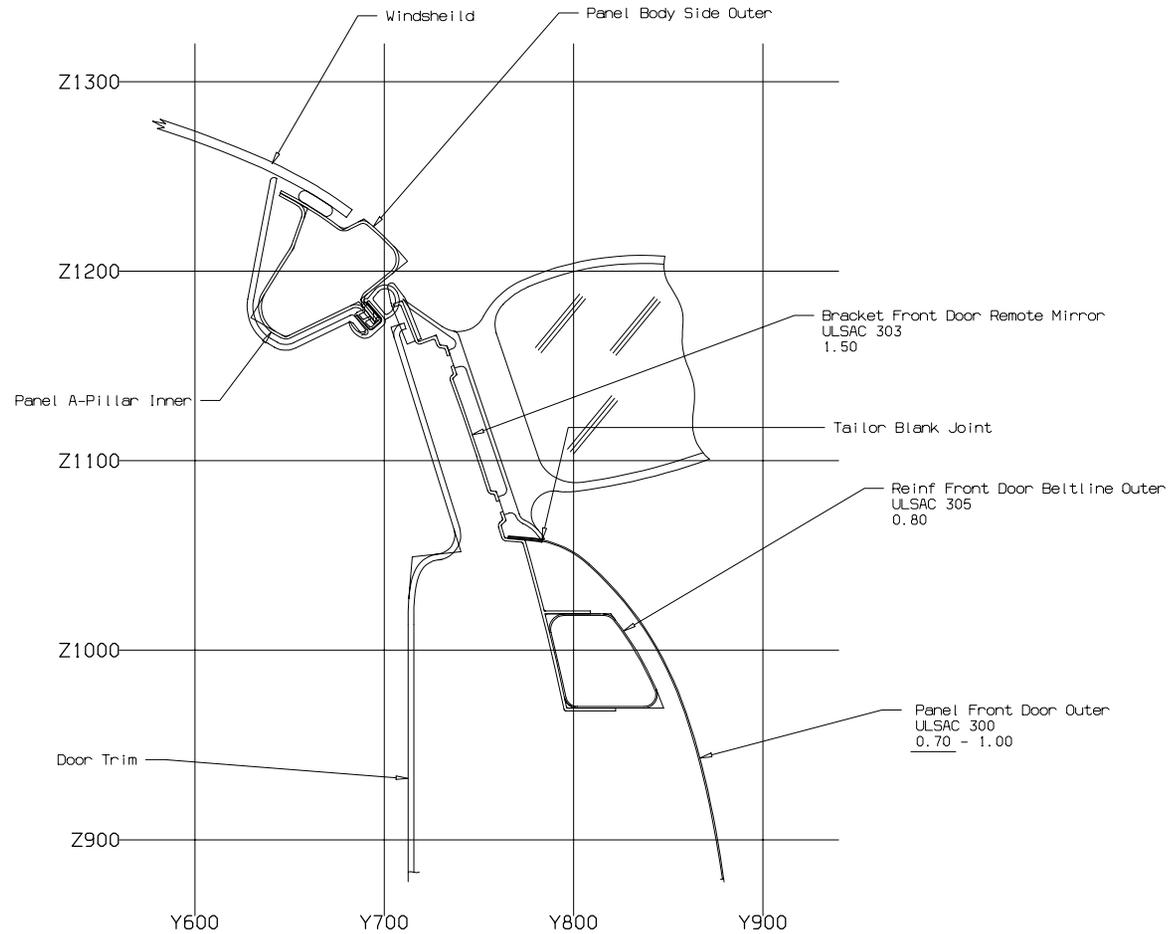




# Conceptual Design

## **Selected Design Concepts - Doors Frameless - Typical Sections**

### **Section H3**

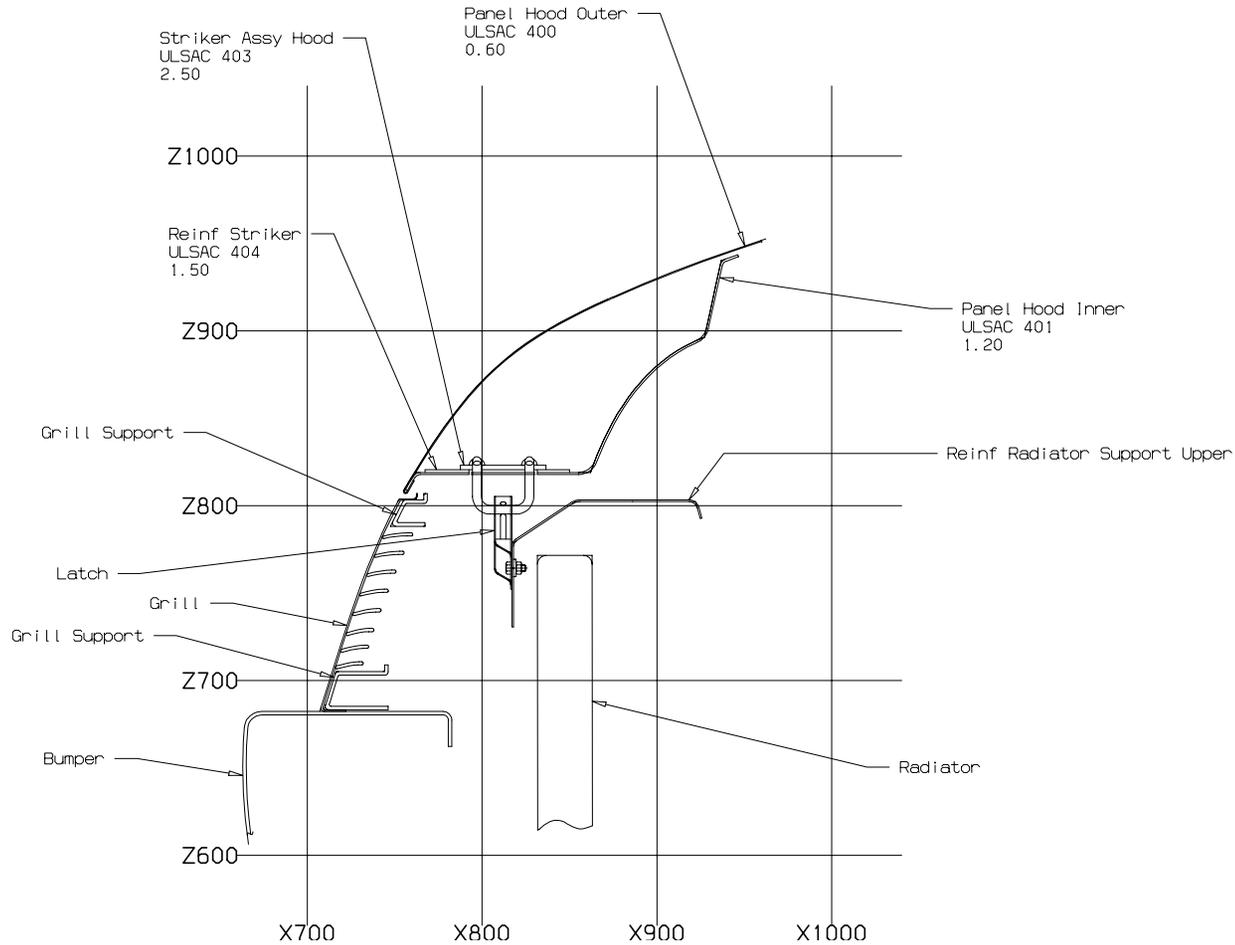




# Conceptual Design

## **Selected Design Concepts - Hoods Conventional - Typical Sections**

### **Section A4**

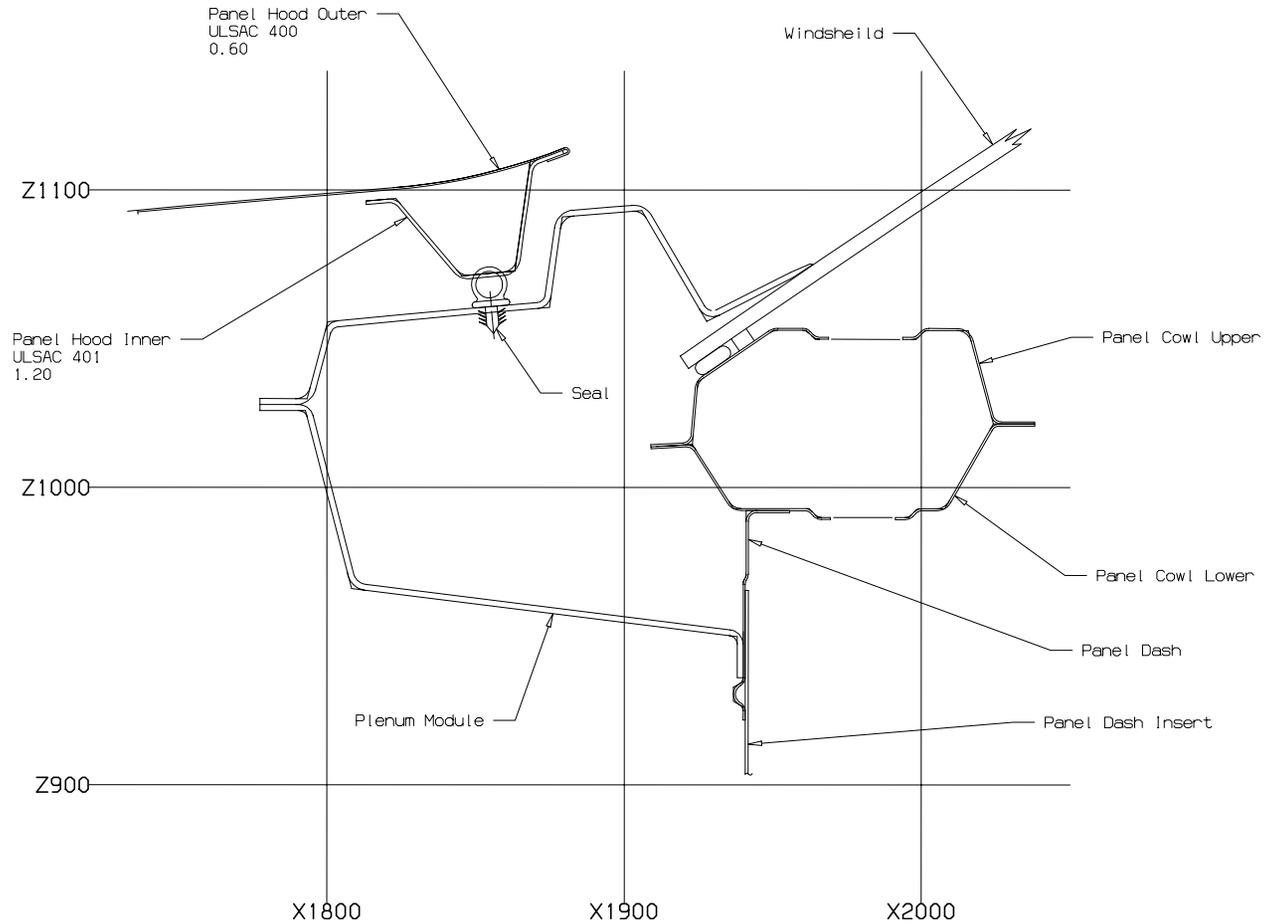




# Conceptual Design

## **Selected Design Concepts - Hoods Conventional - Typical Sections**

### **Section B4**

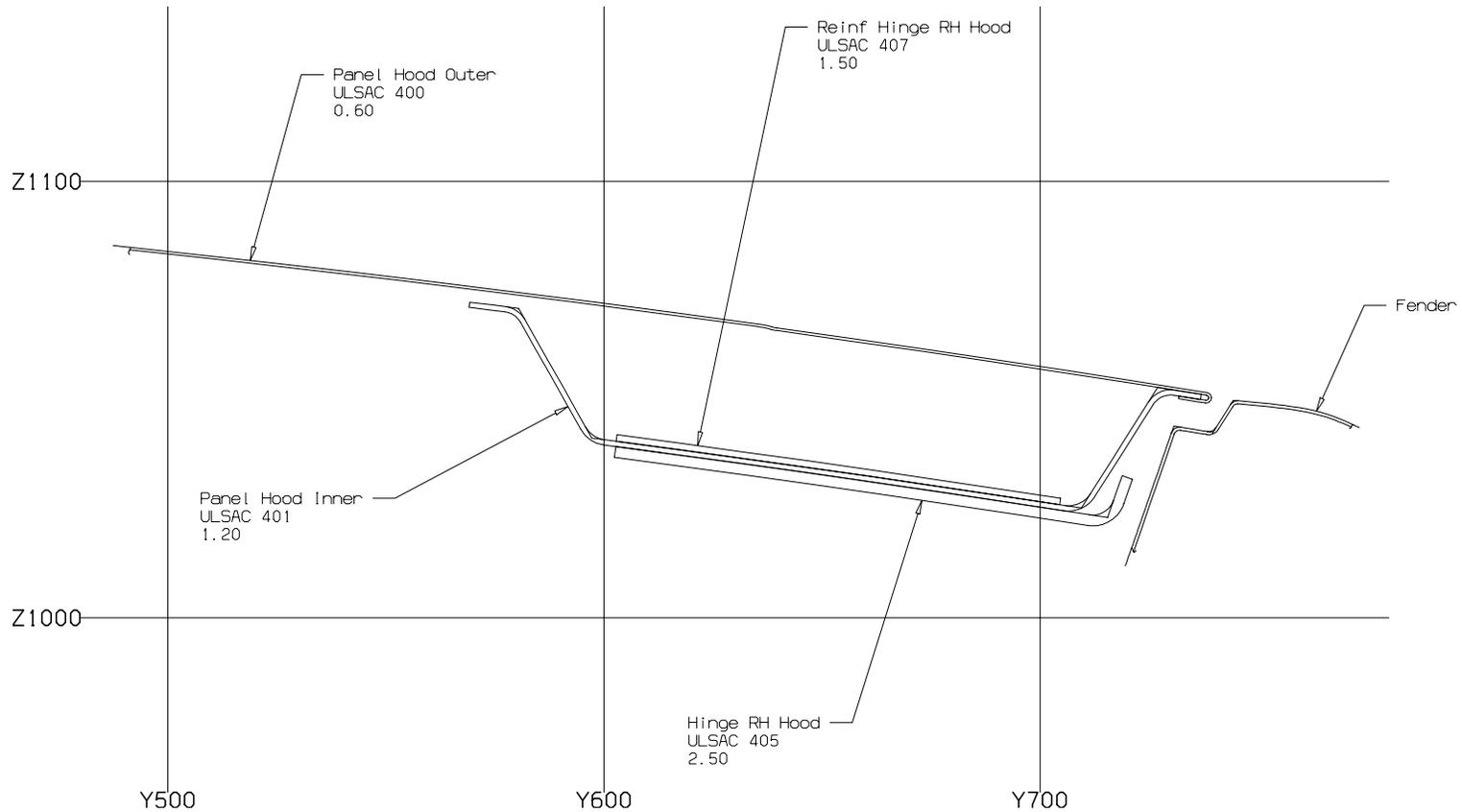




# Conceptual Design

## ***Selected Design Concepts - Hoods Conventional - Typical Sections***

### **Section C4**

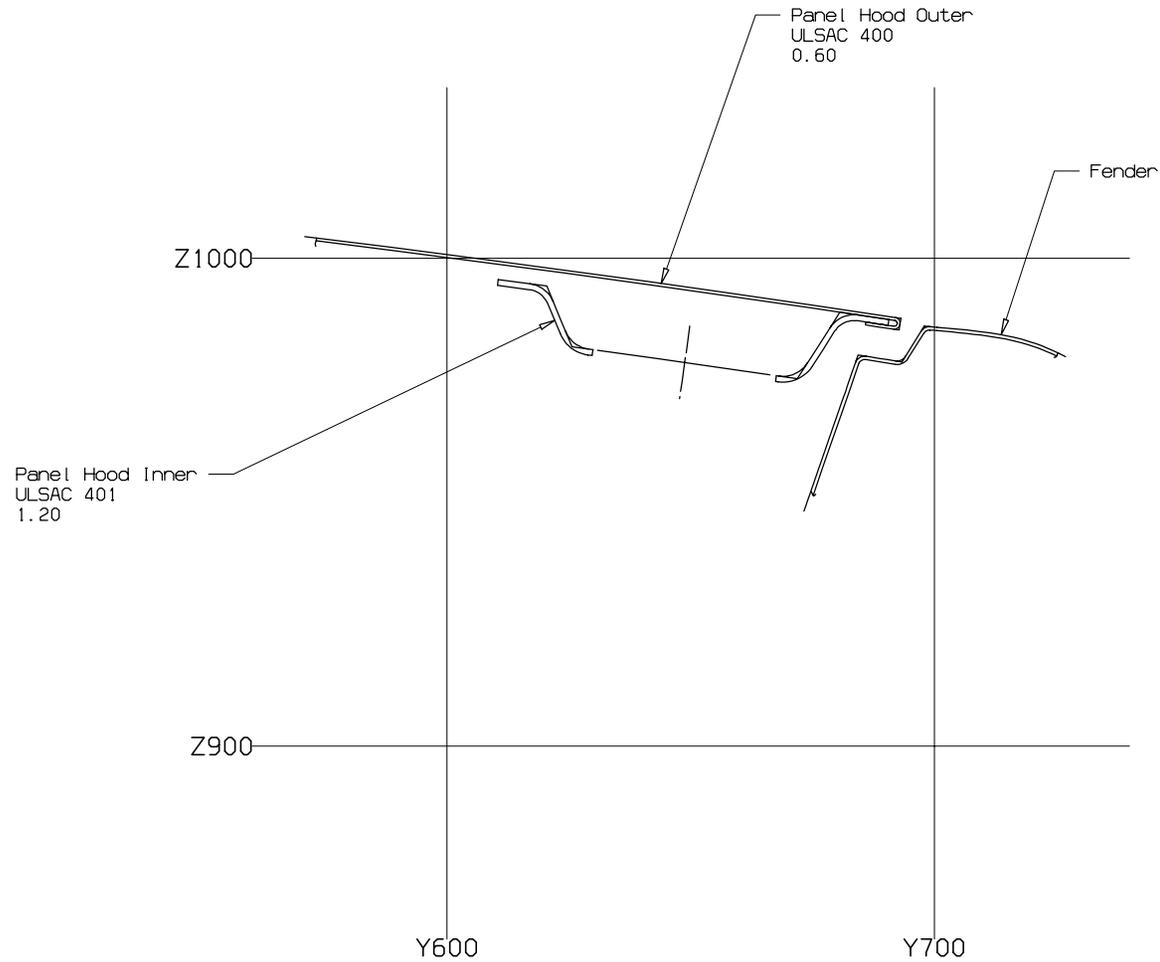




# Conceptual Design

## ***Selected Design Concepts - Hoods Conventional - Typical Sections***

### **Section D4**

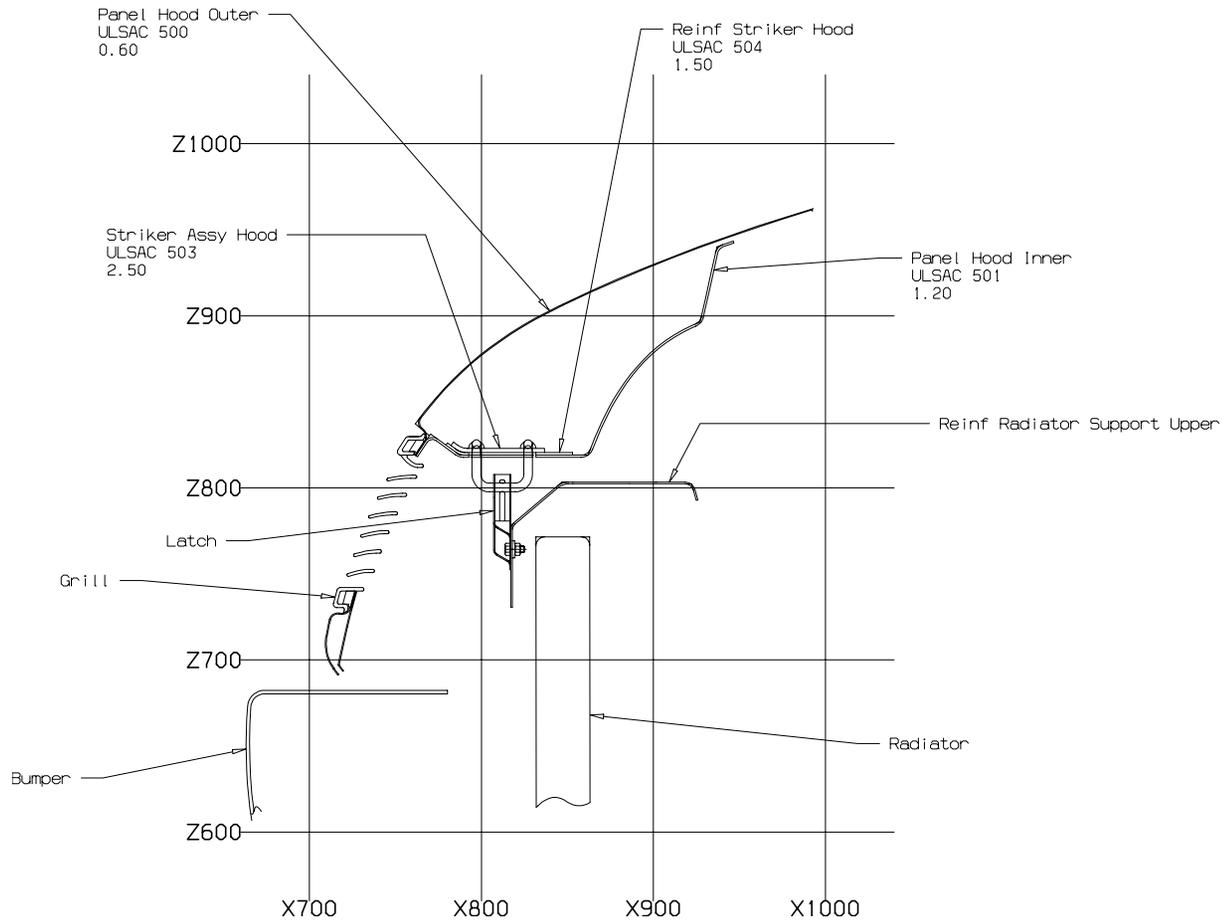




# Conceptual Design

## ***Selected Design Concepts - Hoods Grille Integrated - Typical Sections***

### **Section A5**

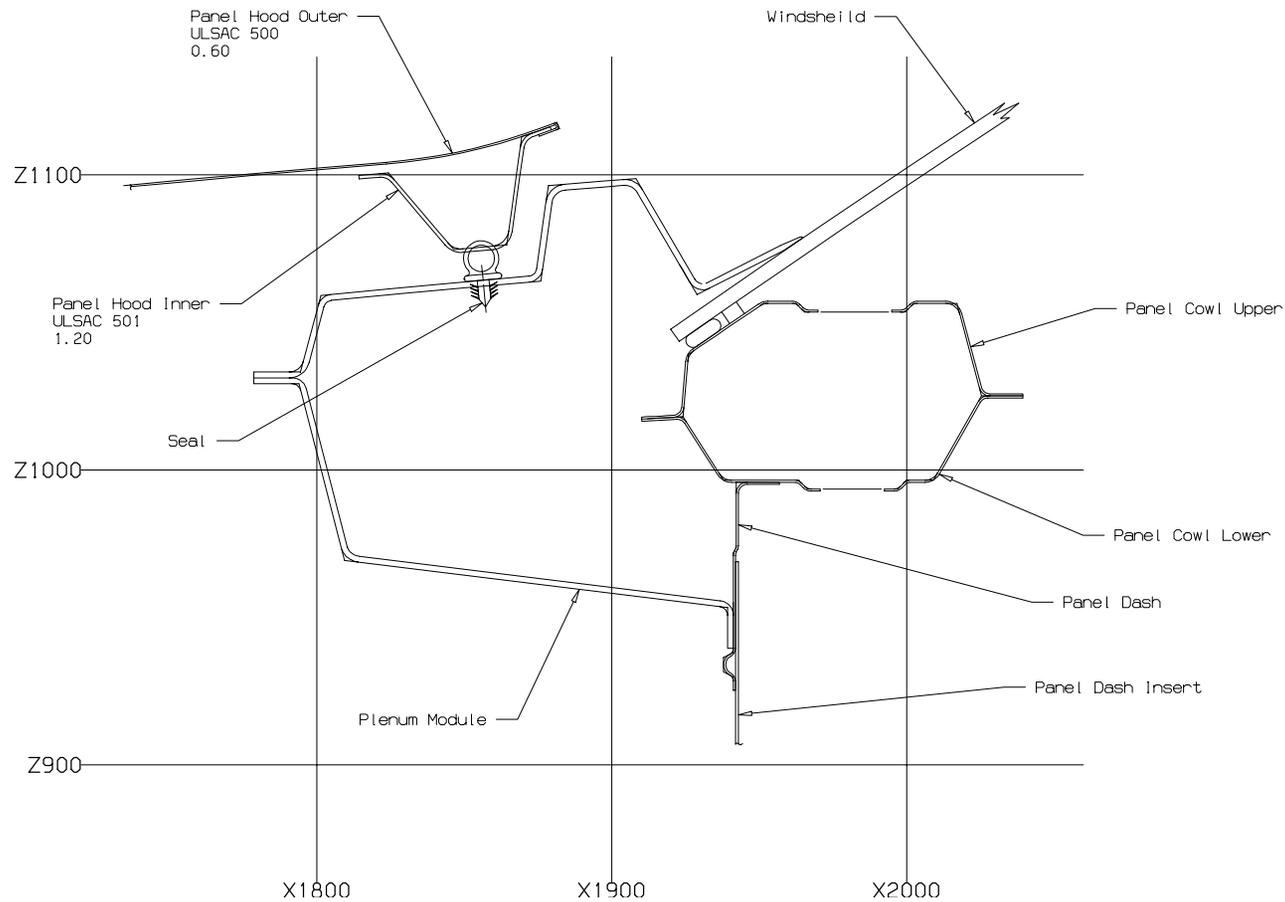




# Conceptual Design

## ***Selected Design Concepts - Hoods Grille Integrated - Typical Sections***

### **Section B5**

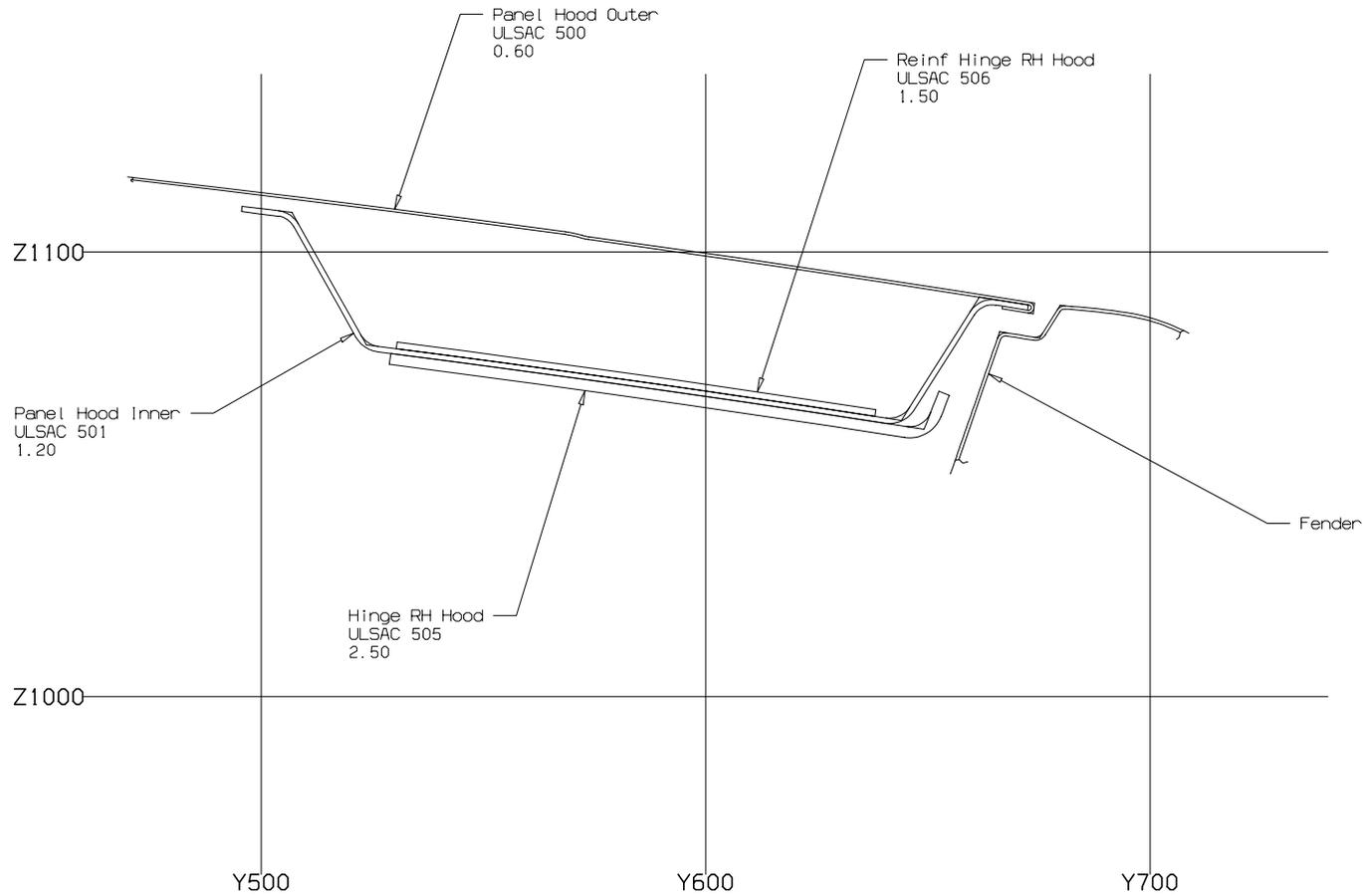




# Conceptual Design

## **Selected Design Concepts - Hoods Grille Integrated - Typical Sections**

### **Section C5**

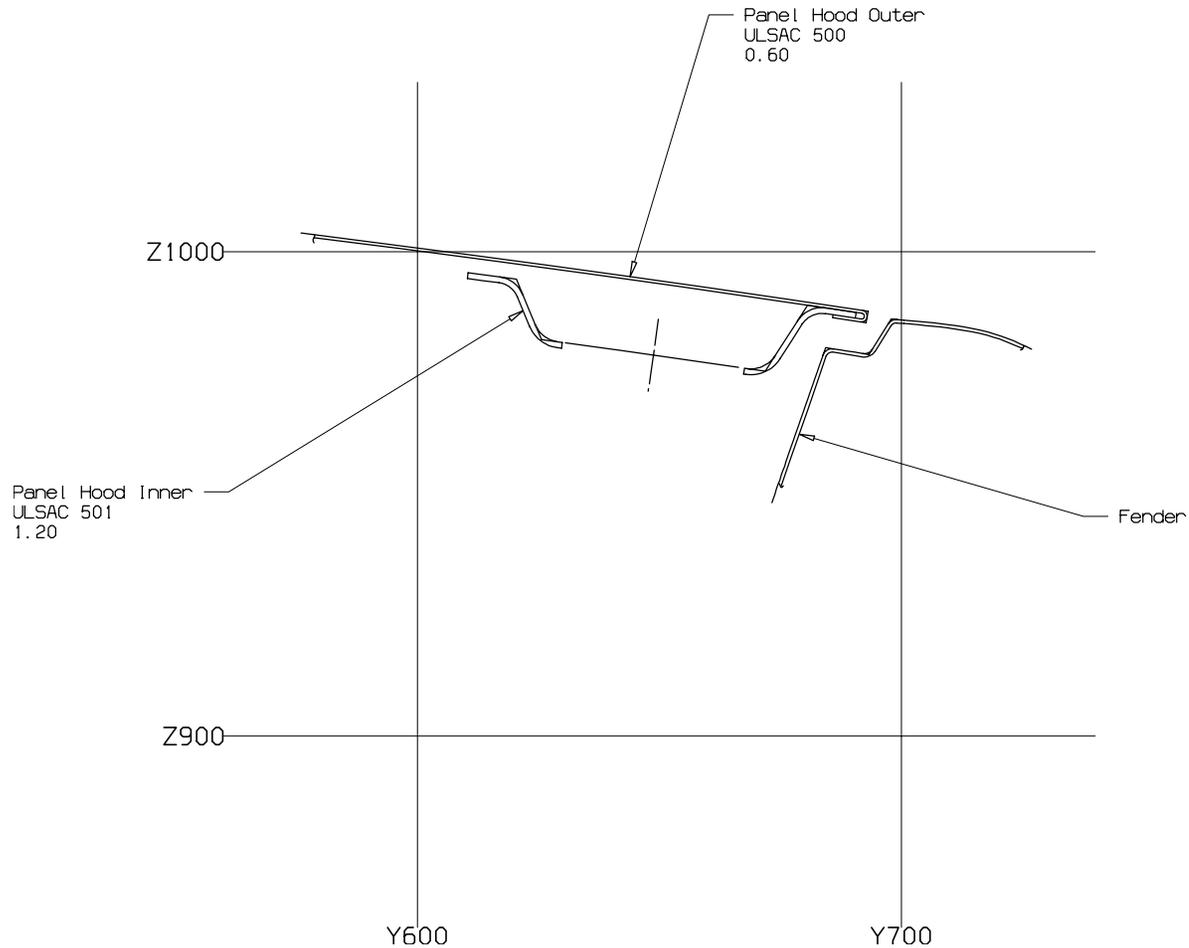




# Conceptual Design

## ***Selected Design Concepts - Hoods Grille Integrated - Typical Sections***

### **Section D5**

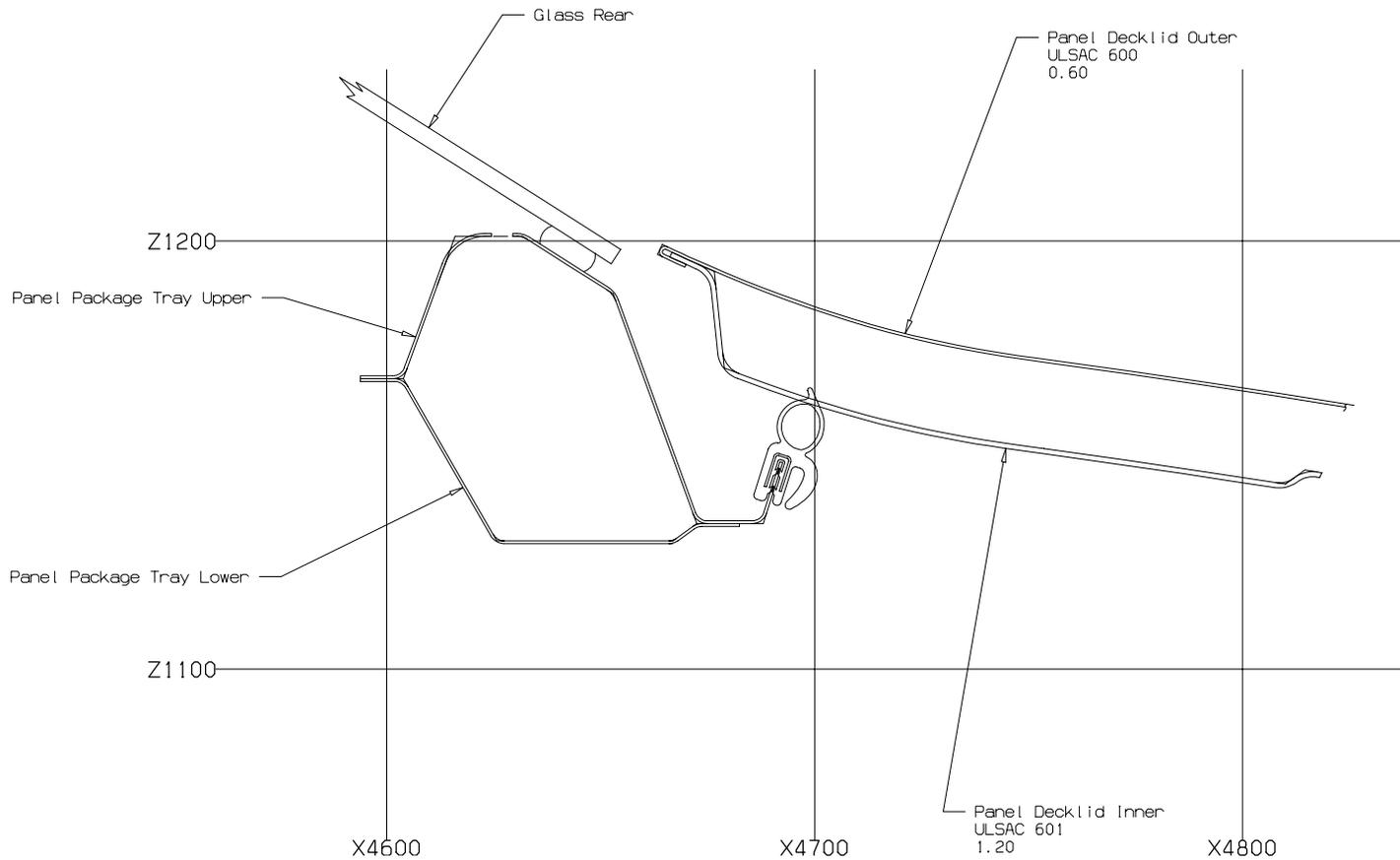




# Conceptual Design

## **Selected Design Concepts - Decklid Conventional - Typical Sections**

### **Section A6**

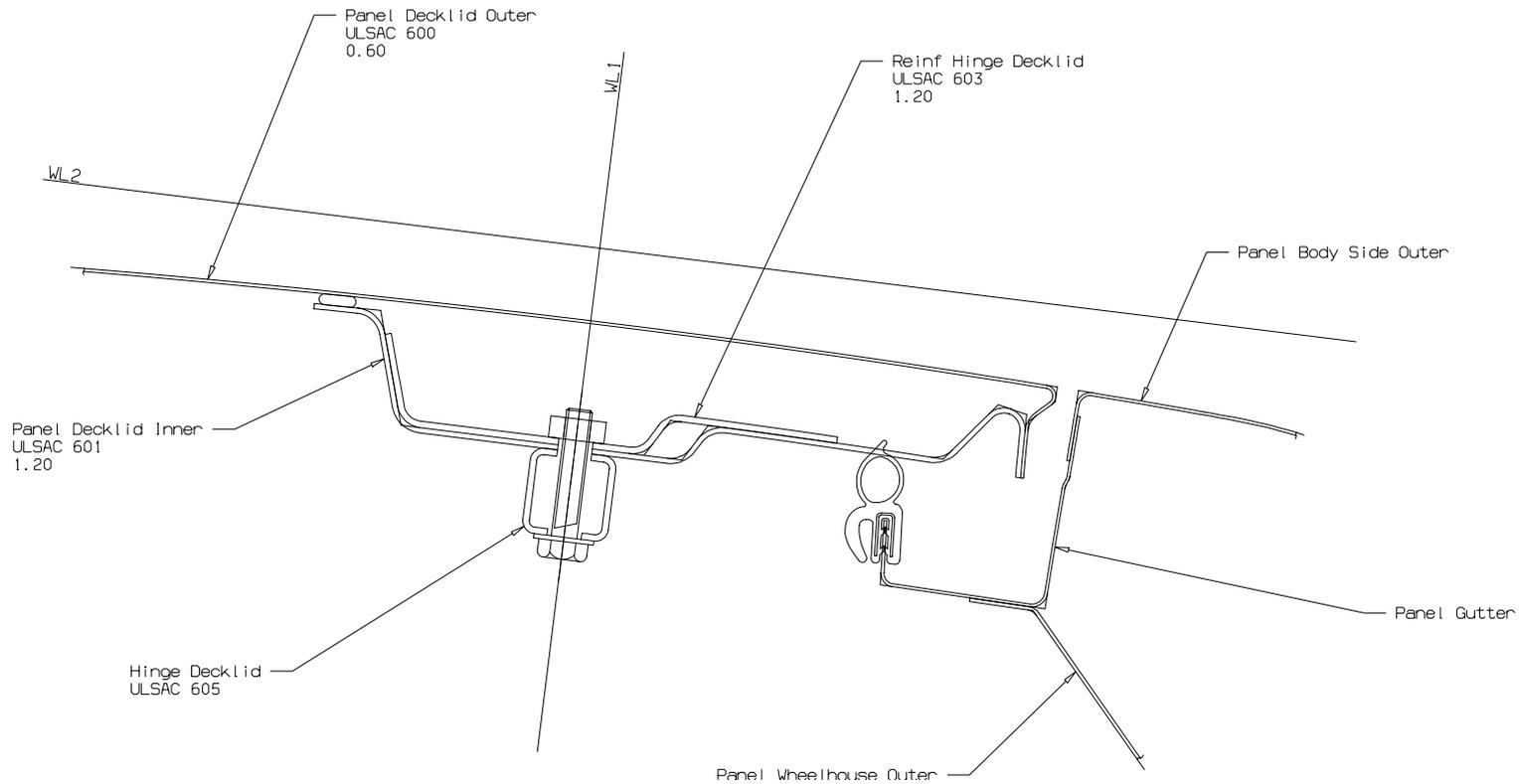




# Conceptual Design

## **Selected Design Concepts - Decklid Conventional - Typical Sections**

### **Section B6**

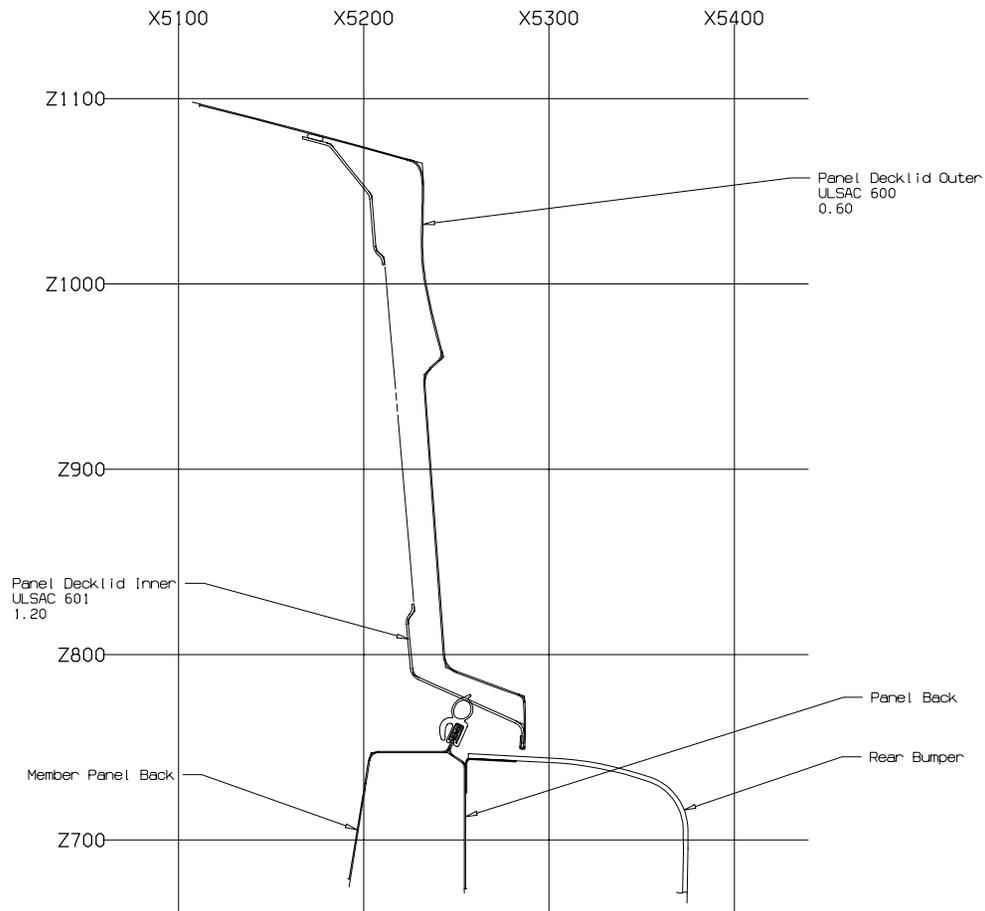




# Conceptual Design

## **Selected Design Concepts - Decklid Conventional - Typical Sections**

### **Section C6**

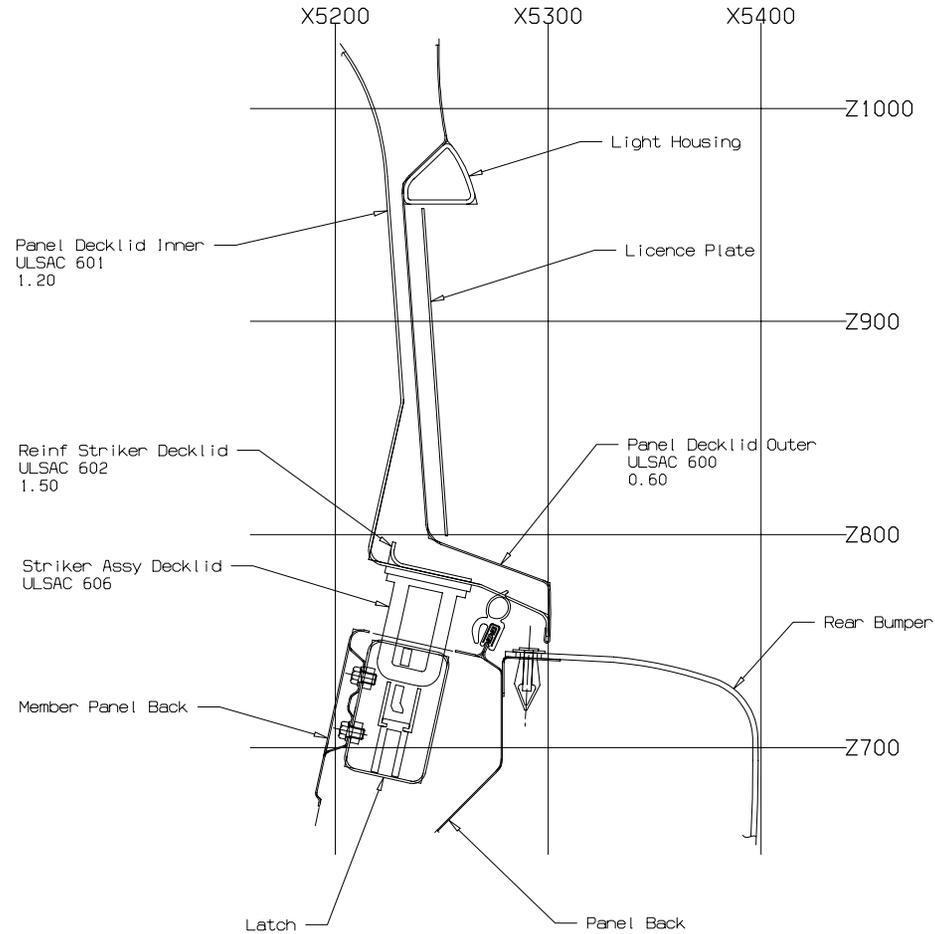




# Conceptual Design

## *Selected Design Concepts - Decklid Conventional - Typical Sections*

### Section D6

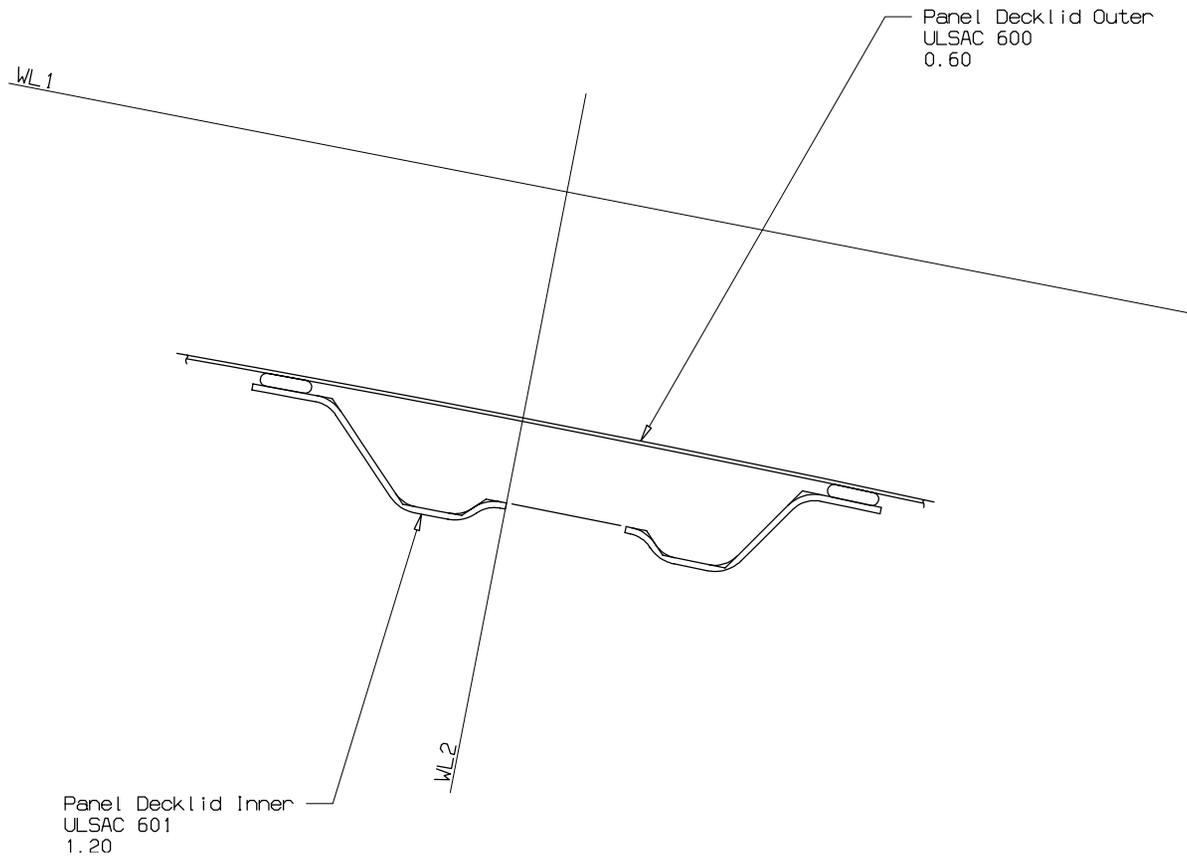




# Conceptual Design

## ***Selected Design Concepts - Decklid Conventional - Typical Sections***

### **Section E6**

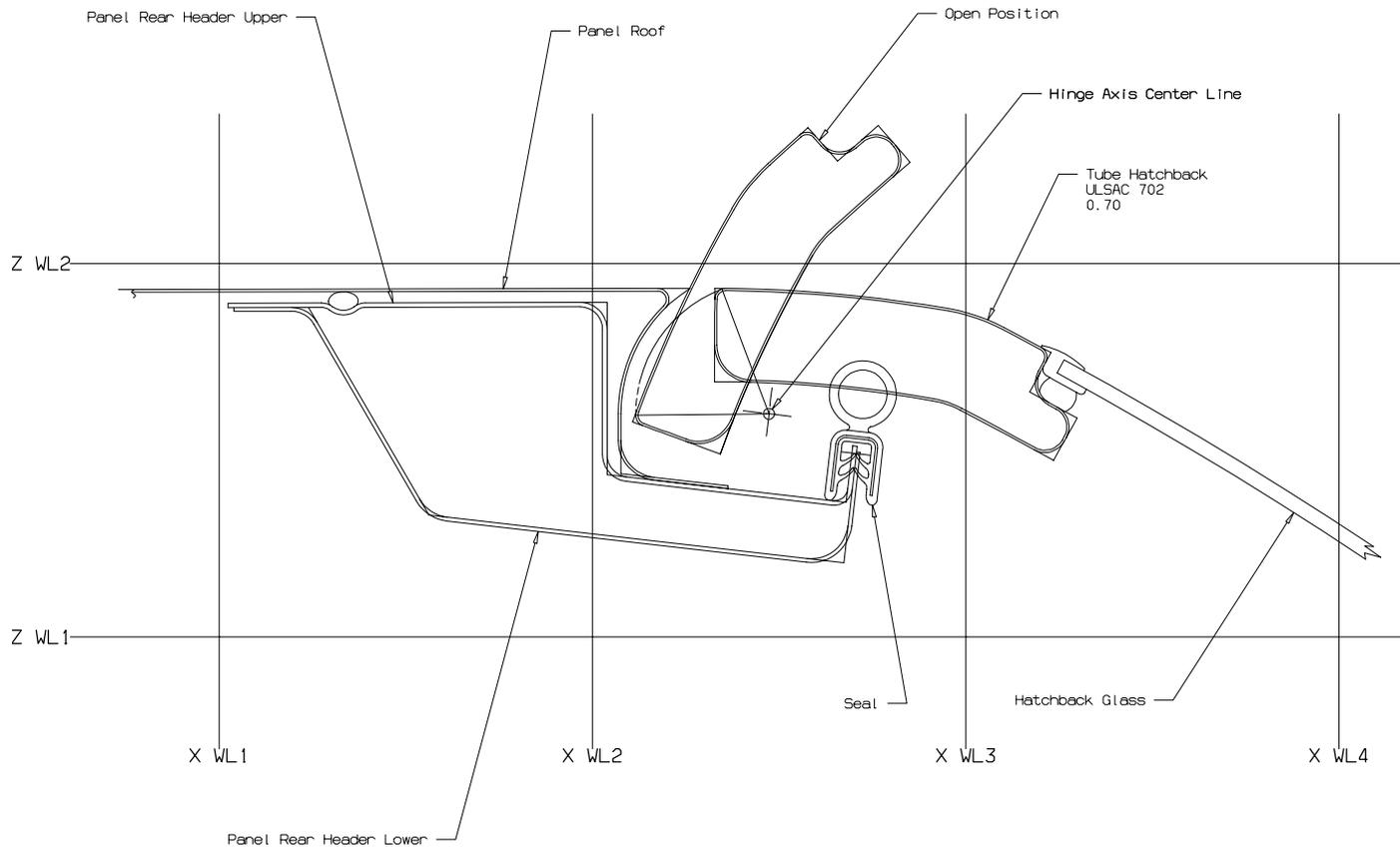




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tube Hydroformed - Typical Sections**

### **Section A7**

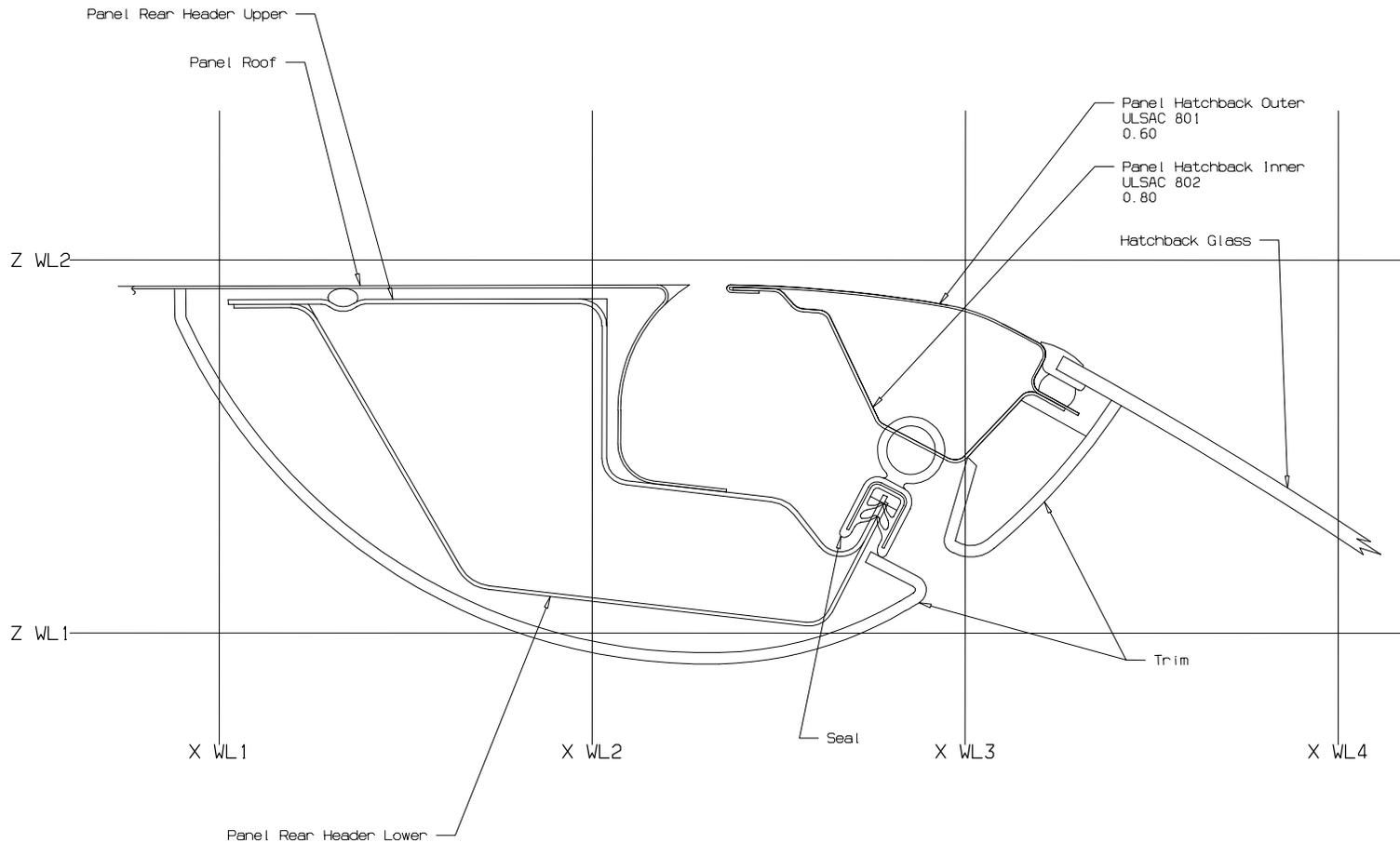




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tailored Blank - Typical Sections**

### **Section A8**

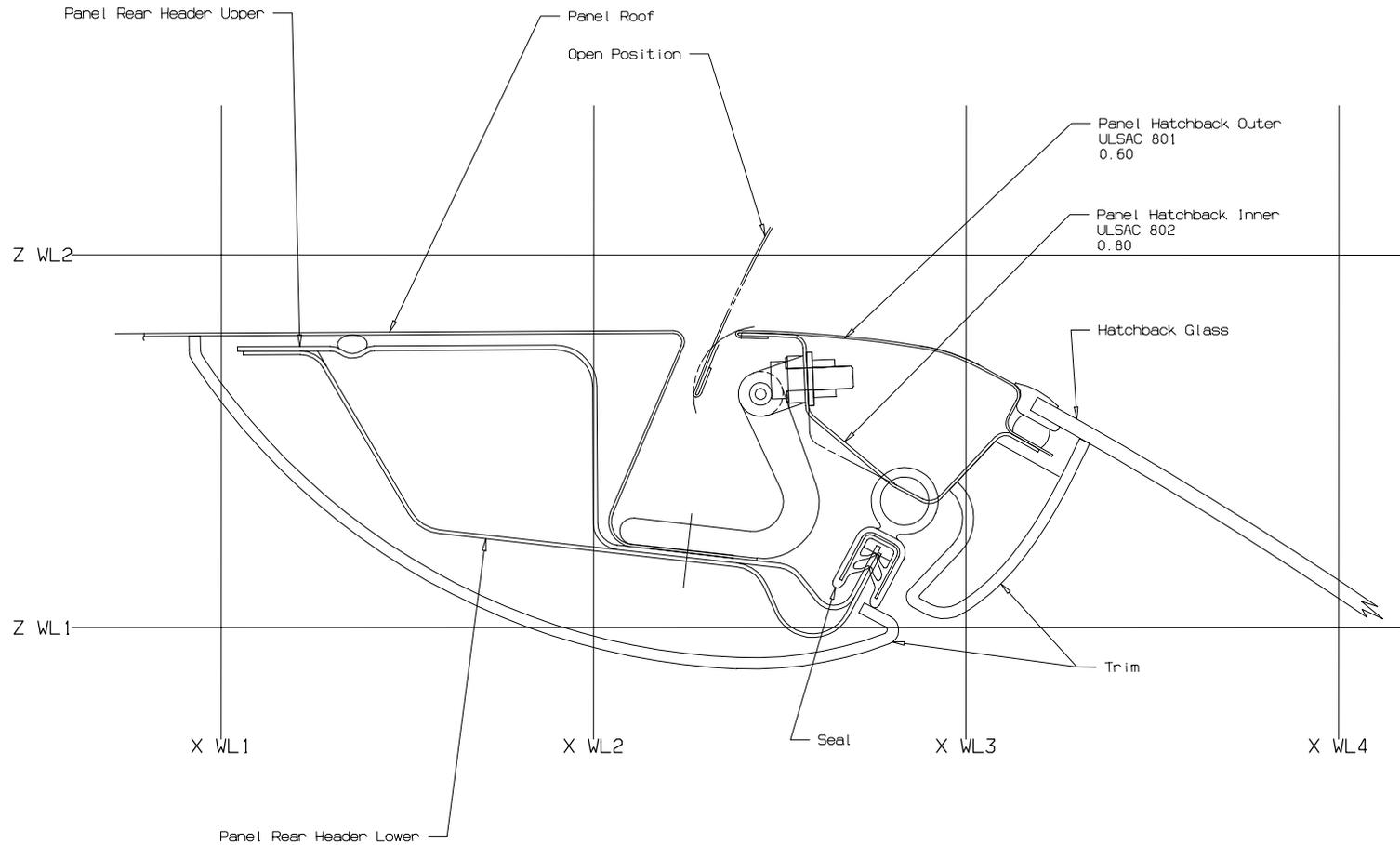




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tailored Blank - Typical Sections**

### **Section B8**

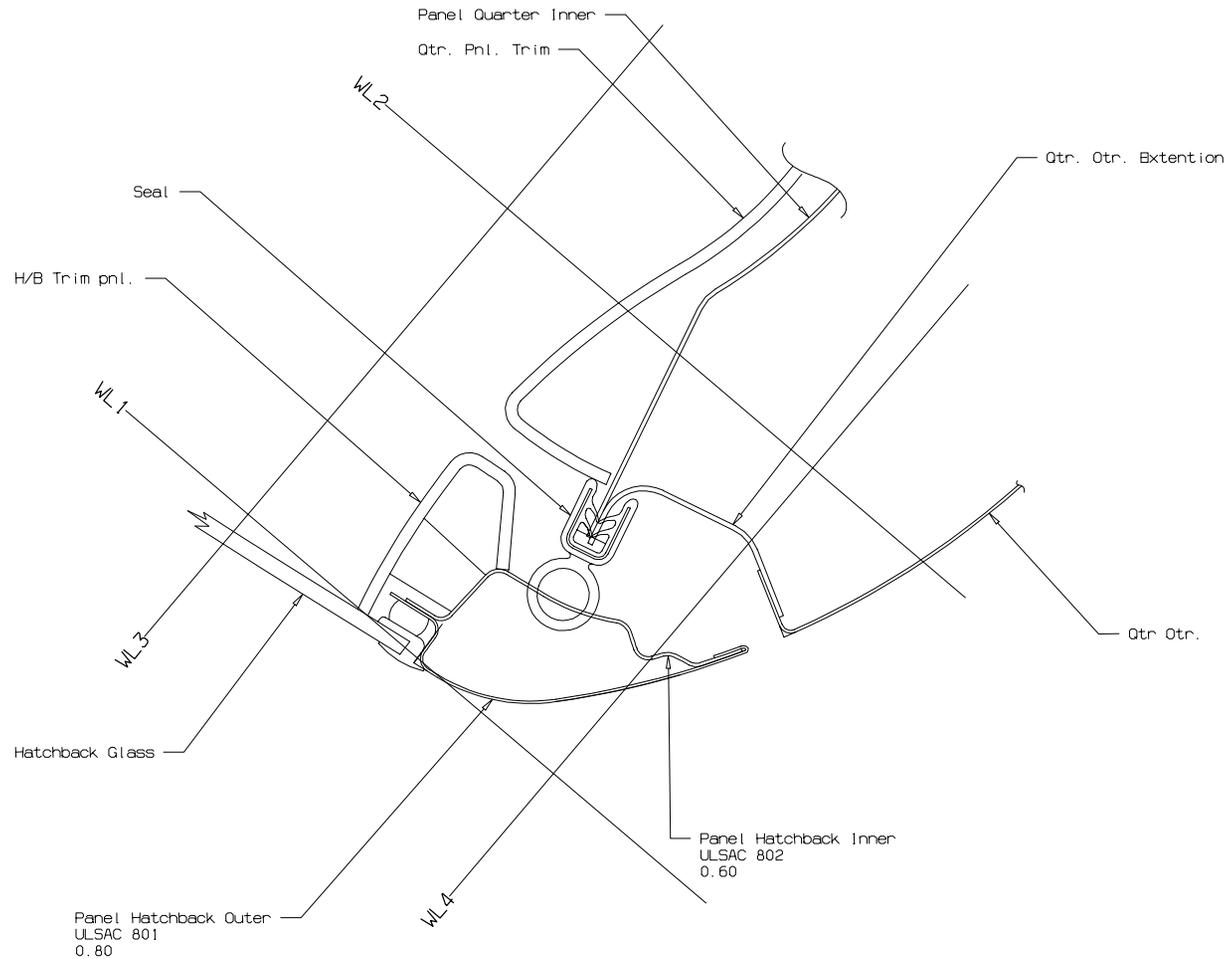




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tailored Blank - Typical Sections**

### **Section C8**

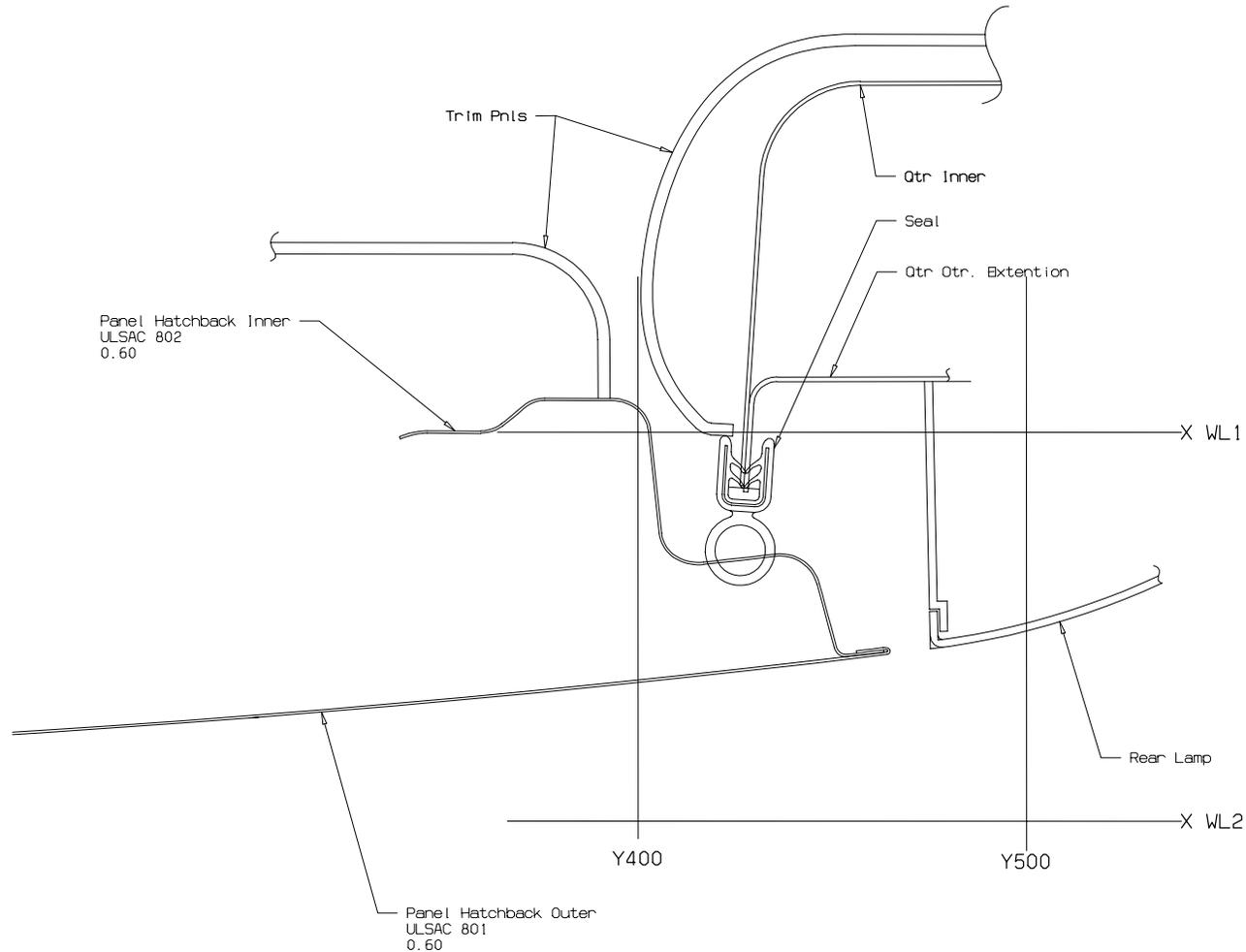




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tailored Blank - Typical Sections**

### **Section D8**

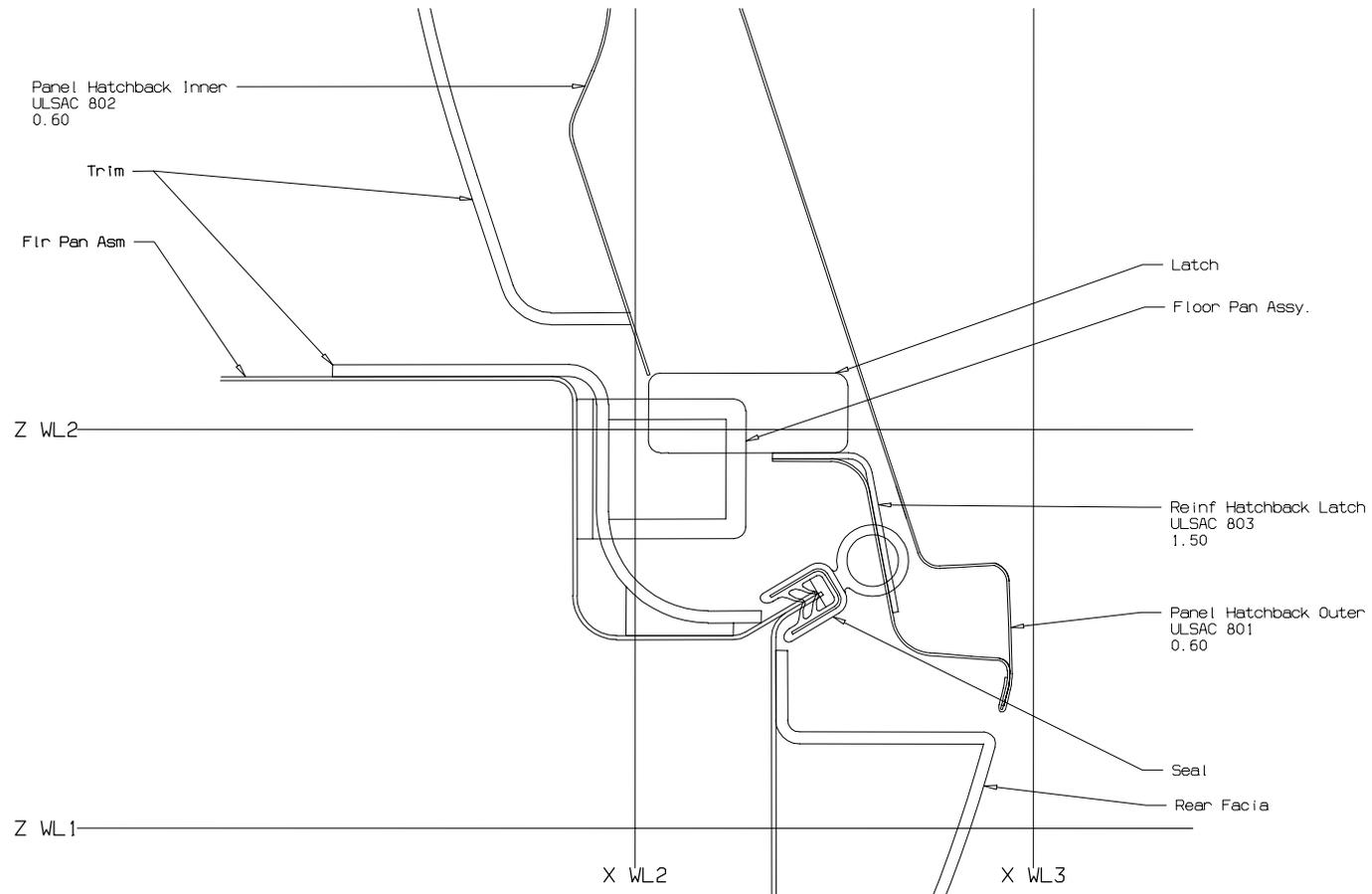




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tailored Blank - Typical Sections**

### **Section E8**

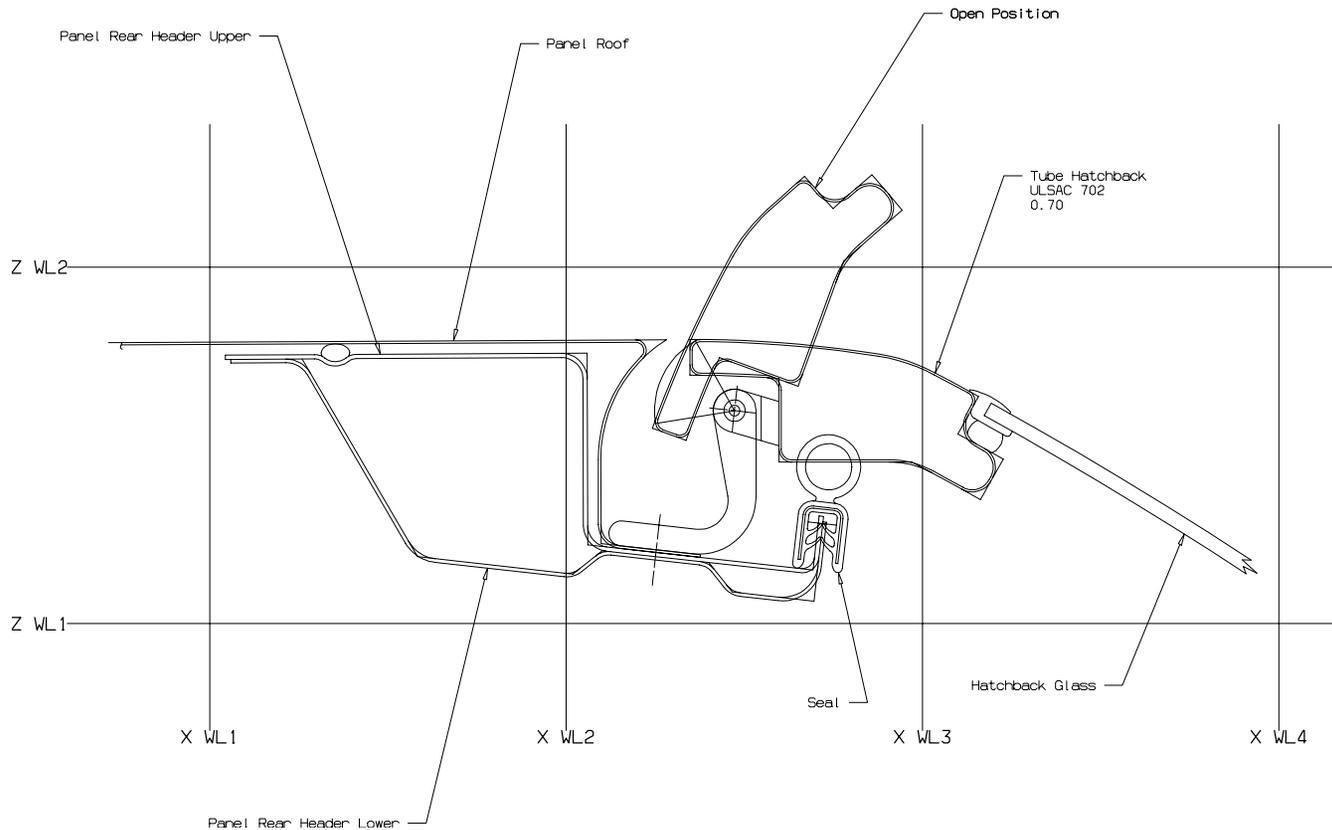




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tube Hydroformed - Typical Sections**

### **Section B7**

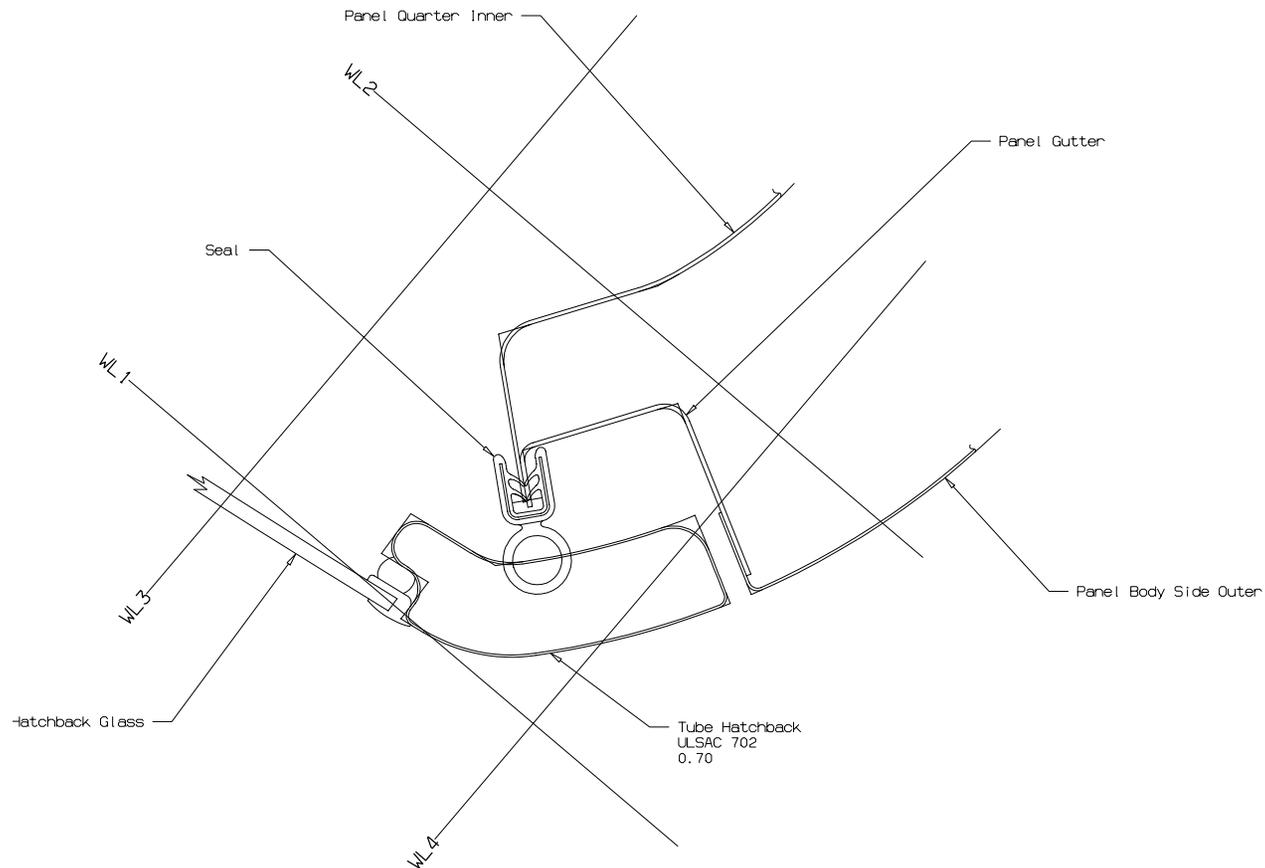




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tube Hydroformed - Typical Sections**

### **Section C7**

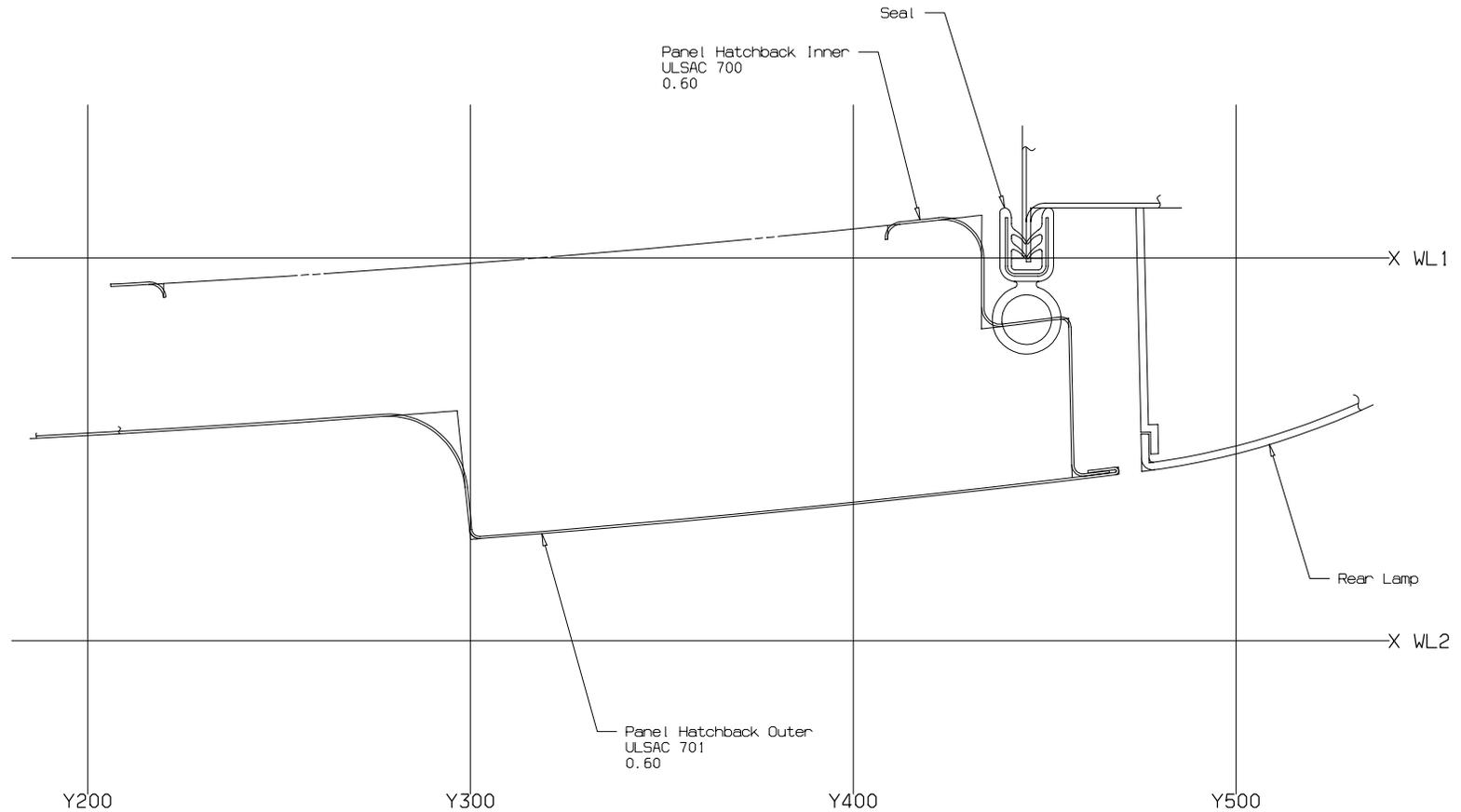




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tube Hydroformed - Typical Sections**

### **Section D7**

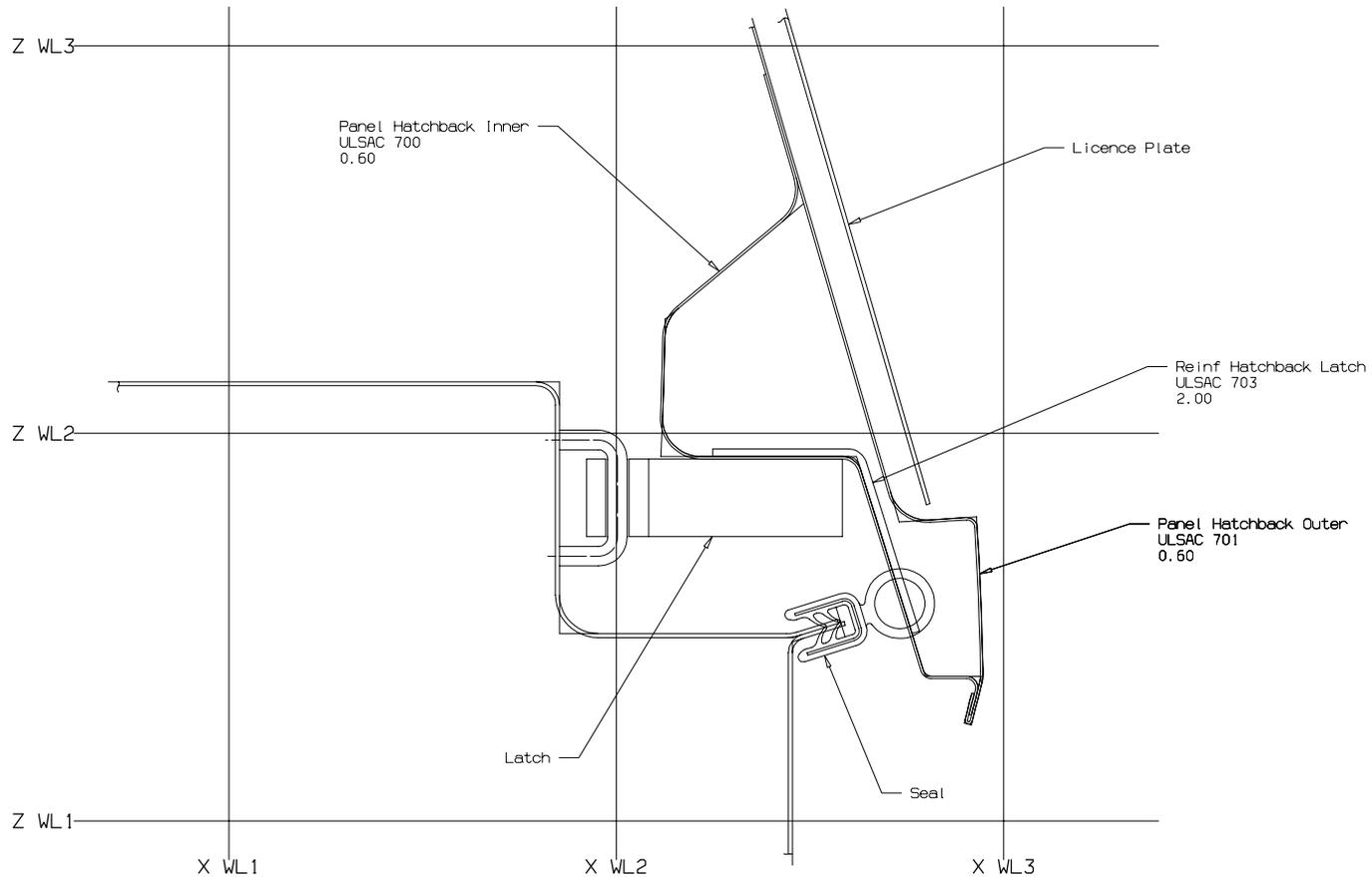




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Tube Hydroformed - Typical Sections**

### **Section E7**

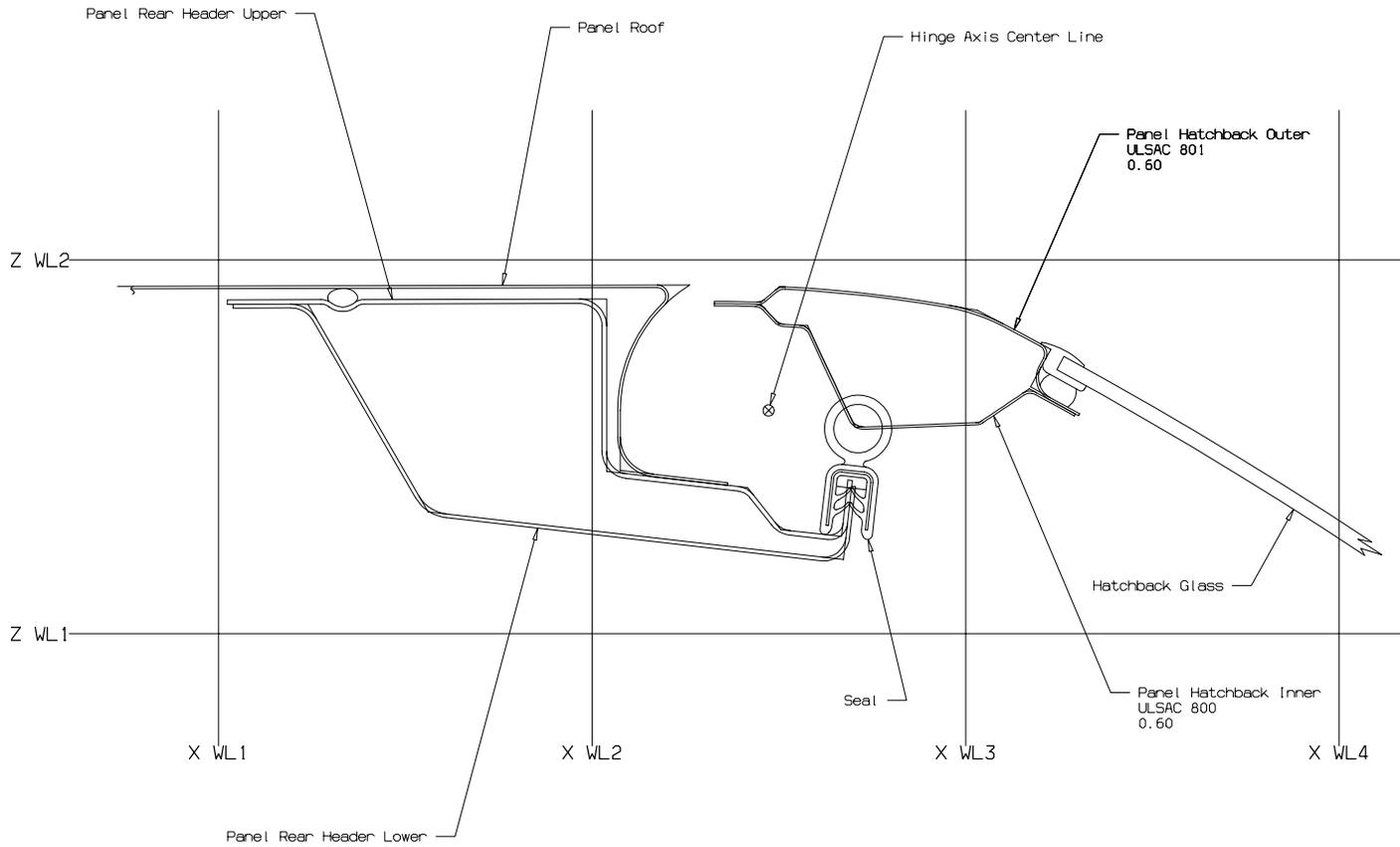




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Sheet Hydroformed - Typical Sections**

### **Section A9.5**

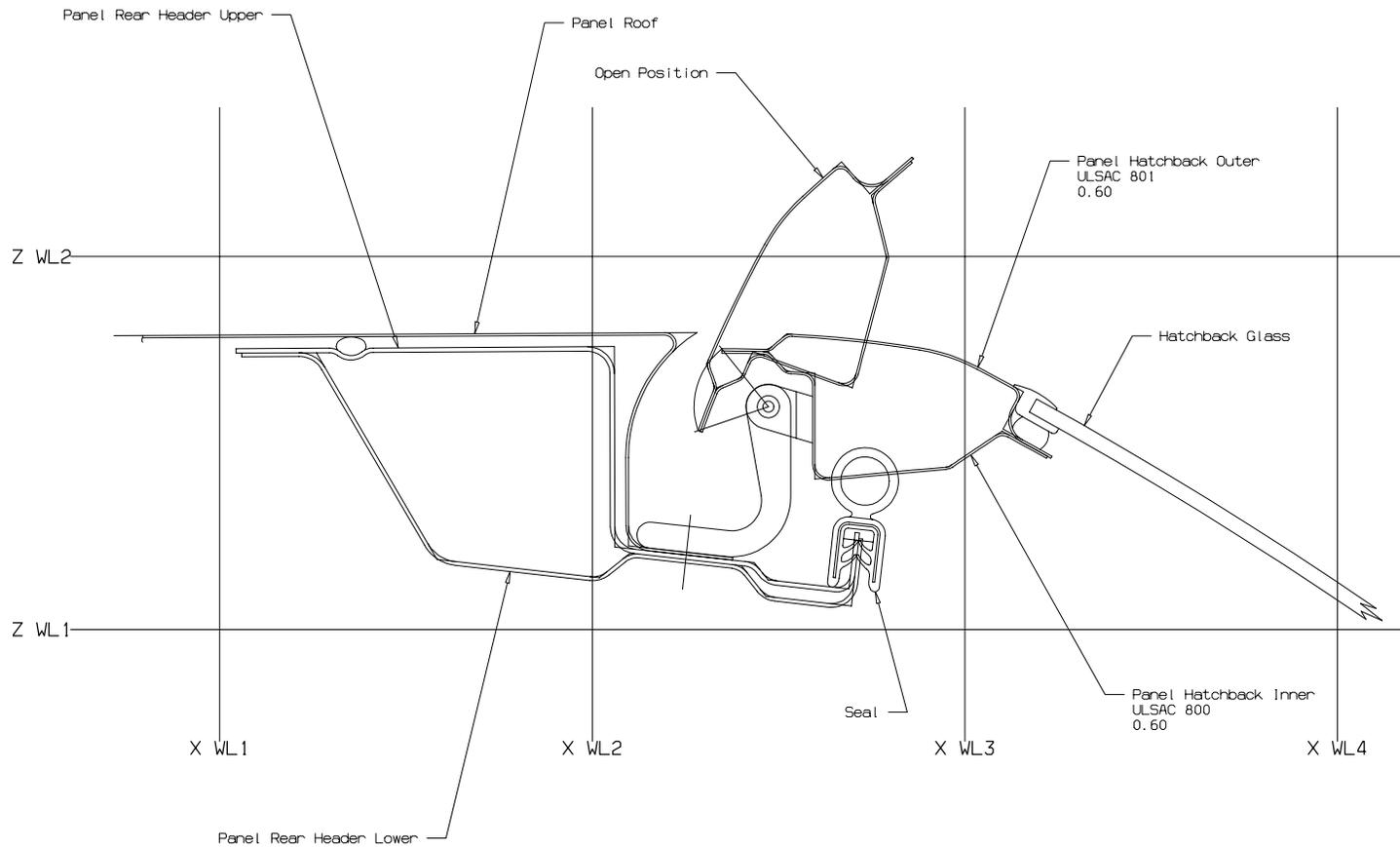




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Sheet Hydroformed - Typical Sections**

### **Section B9.5**

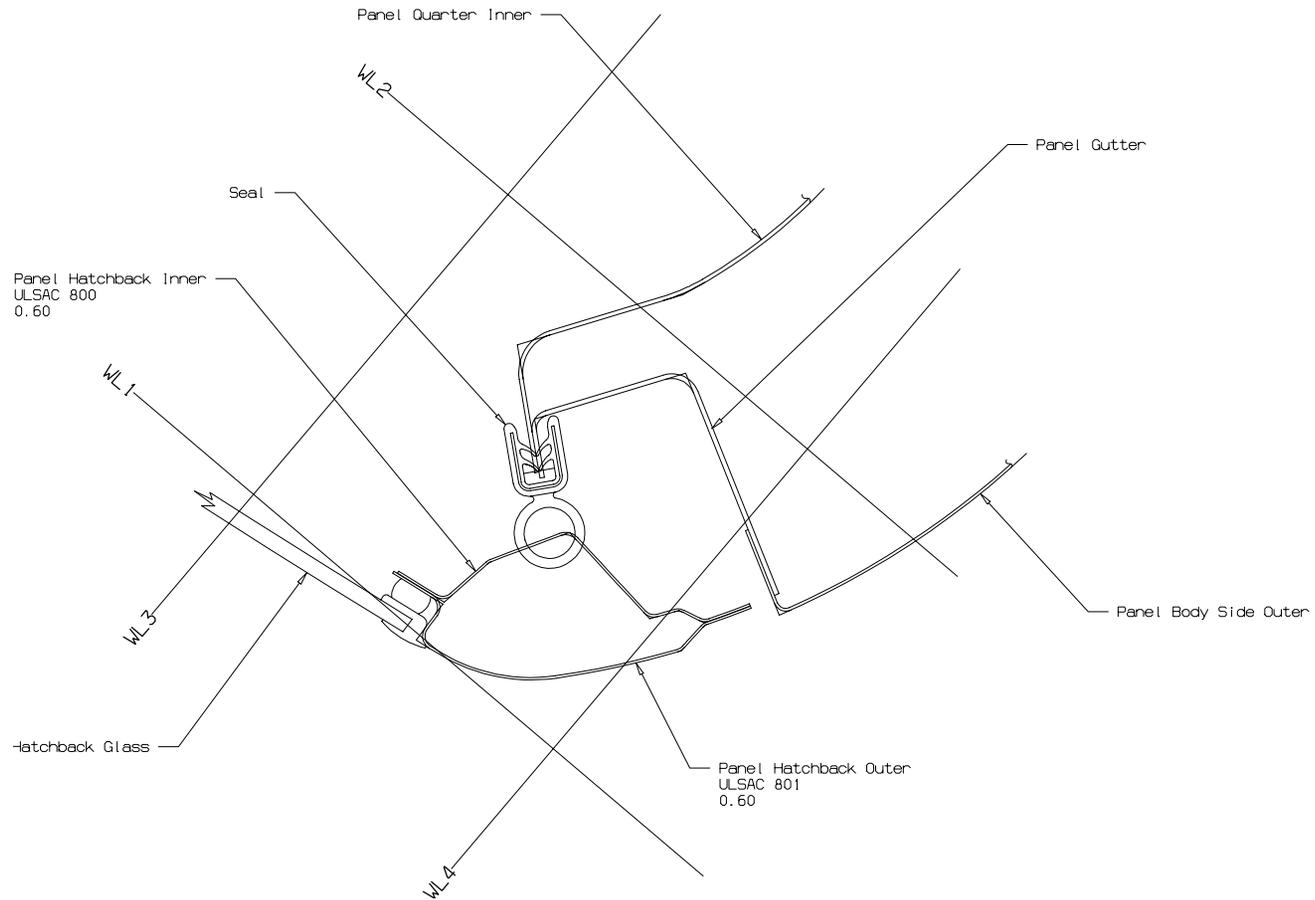




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Sheet Hydroformed - Typical Sections**

### **Section C9.5**

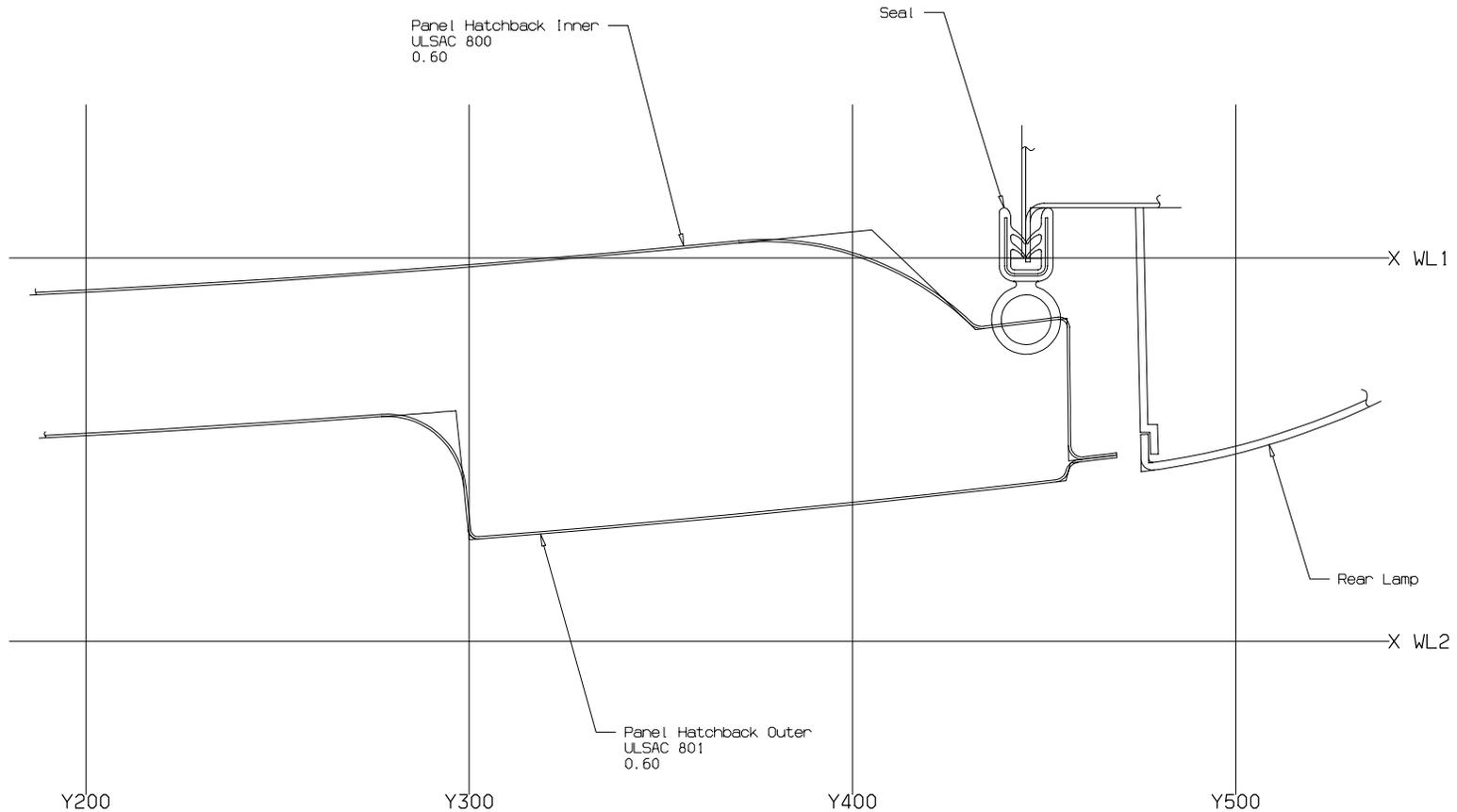




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Sheet Hydroformed - Typical Sections**

### **Section D9.5**

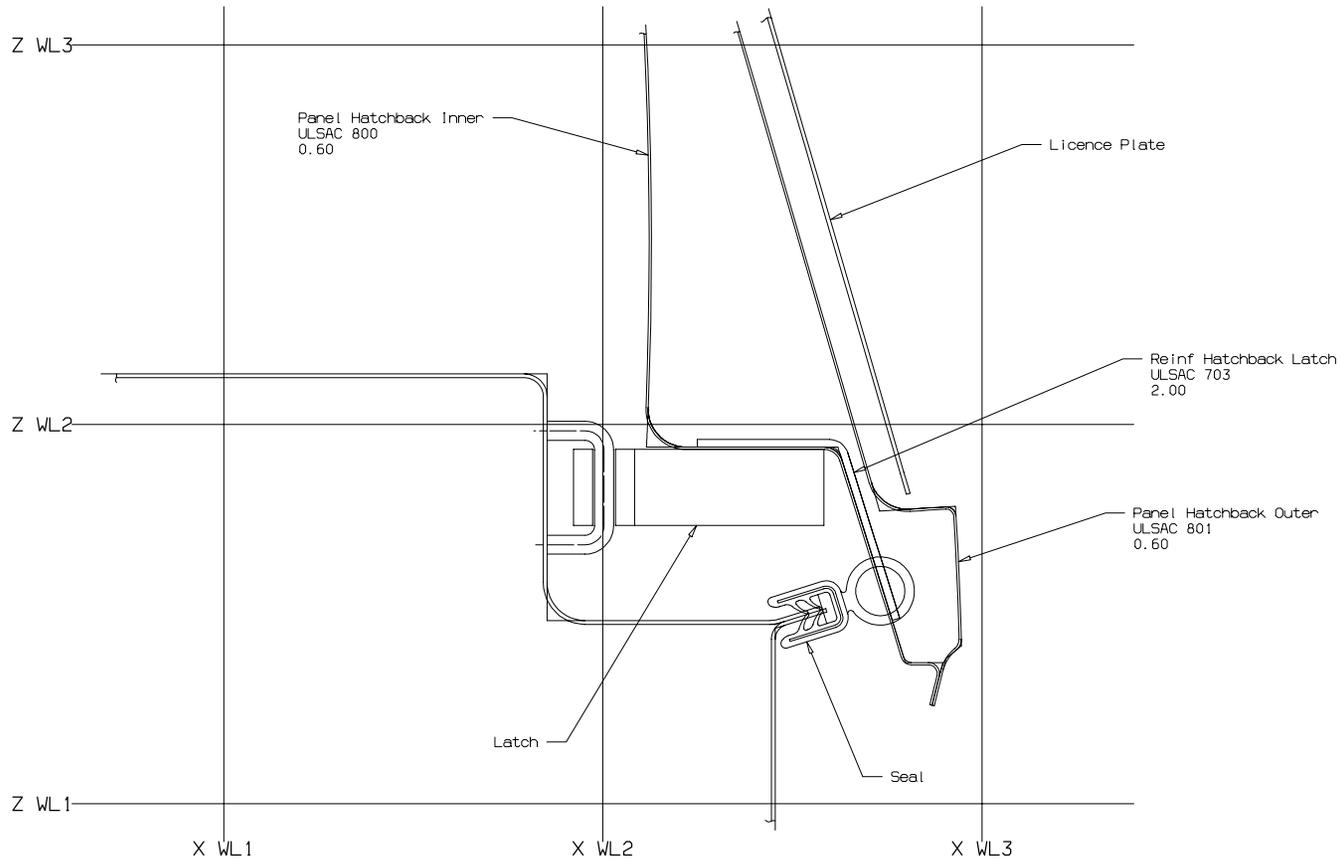




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Sheet Hydroformed - Typical Sections**

### **Section E9.5**

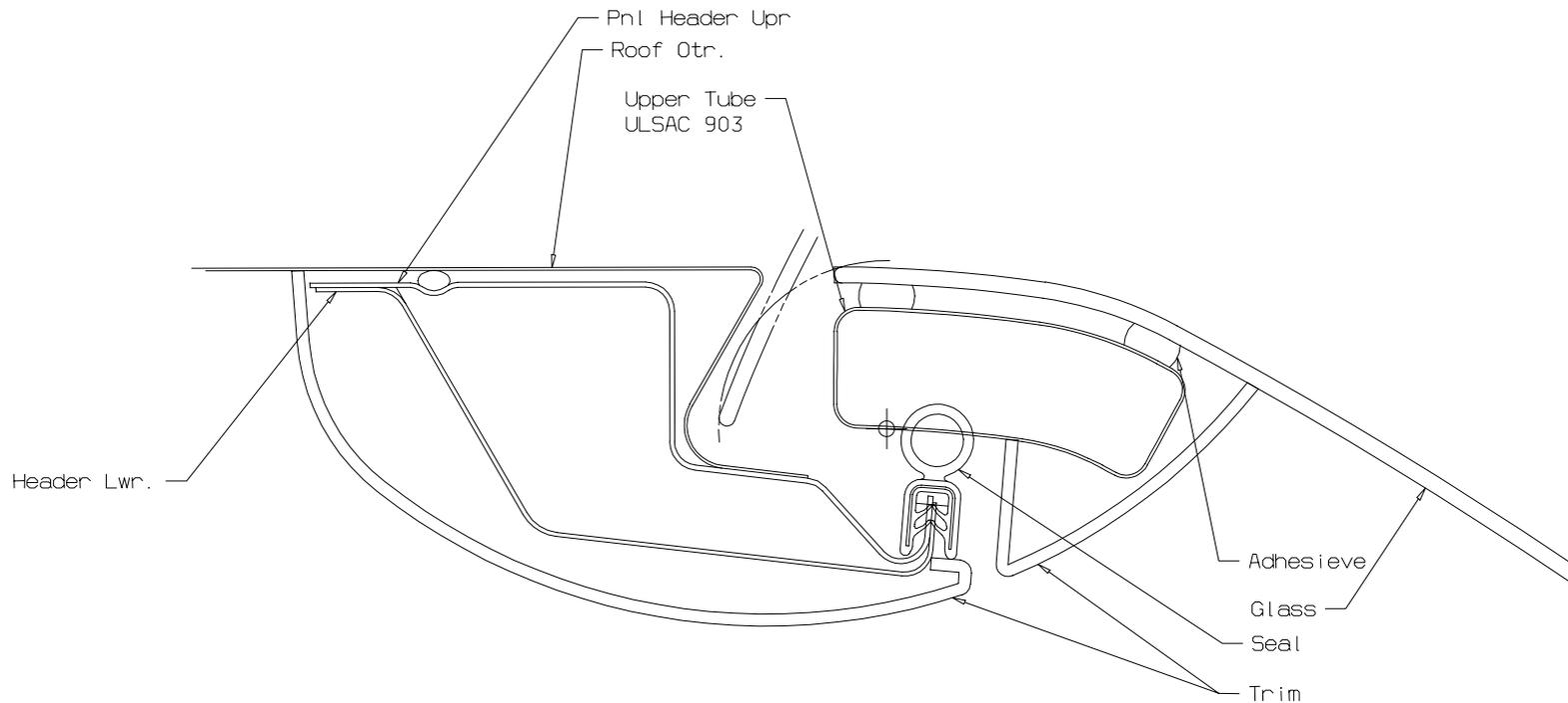




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Hydroformed Ring - Typical Sections**

### **Section A9**

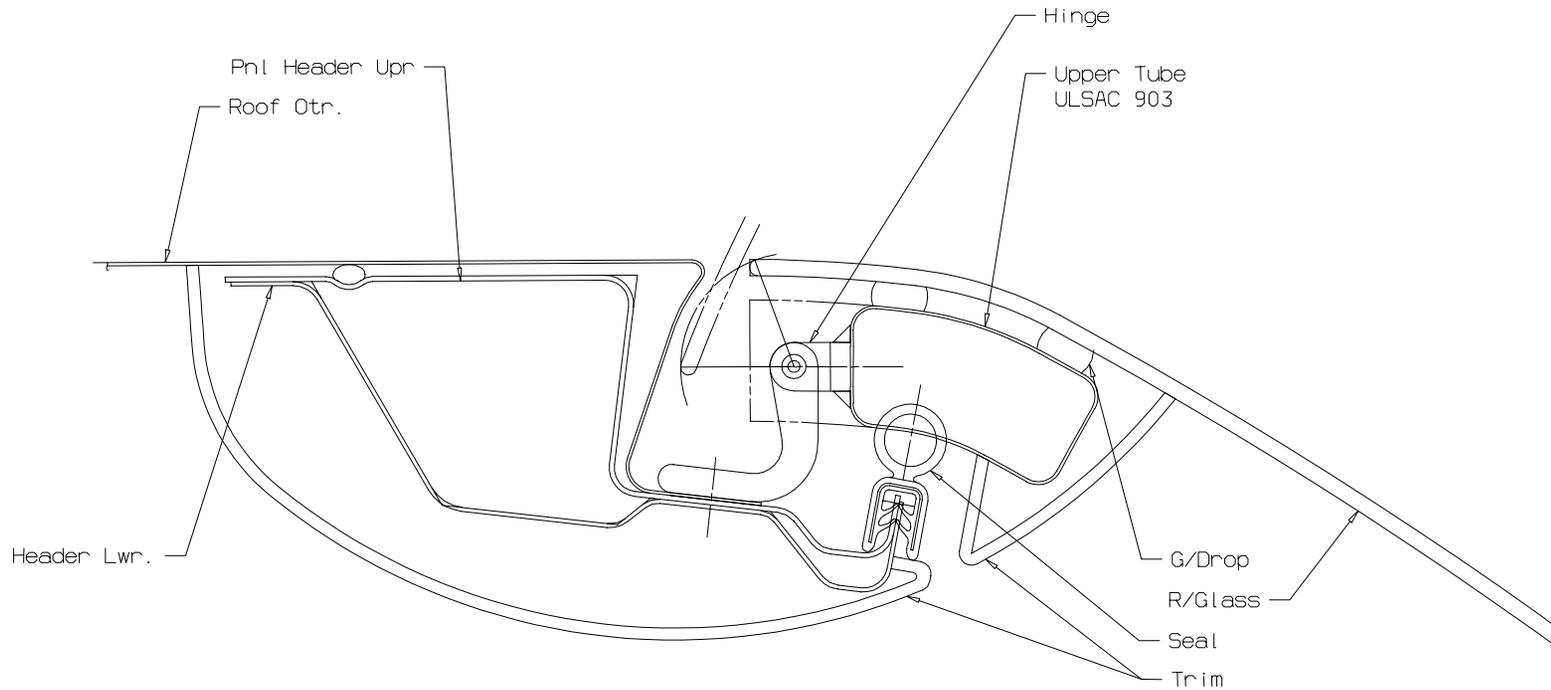




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Hydroformed Ring - Typical Sections**

### **Section B9**

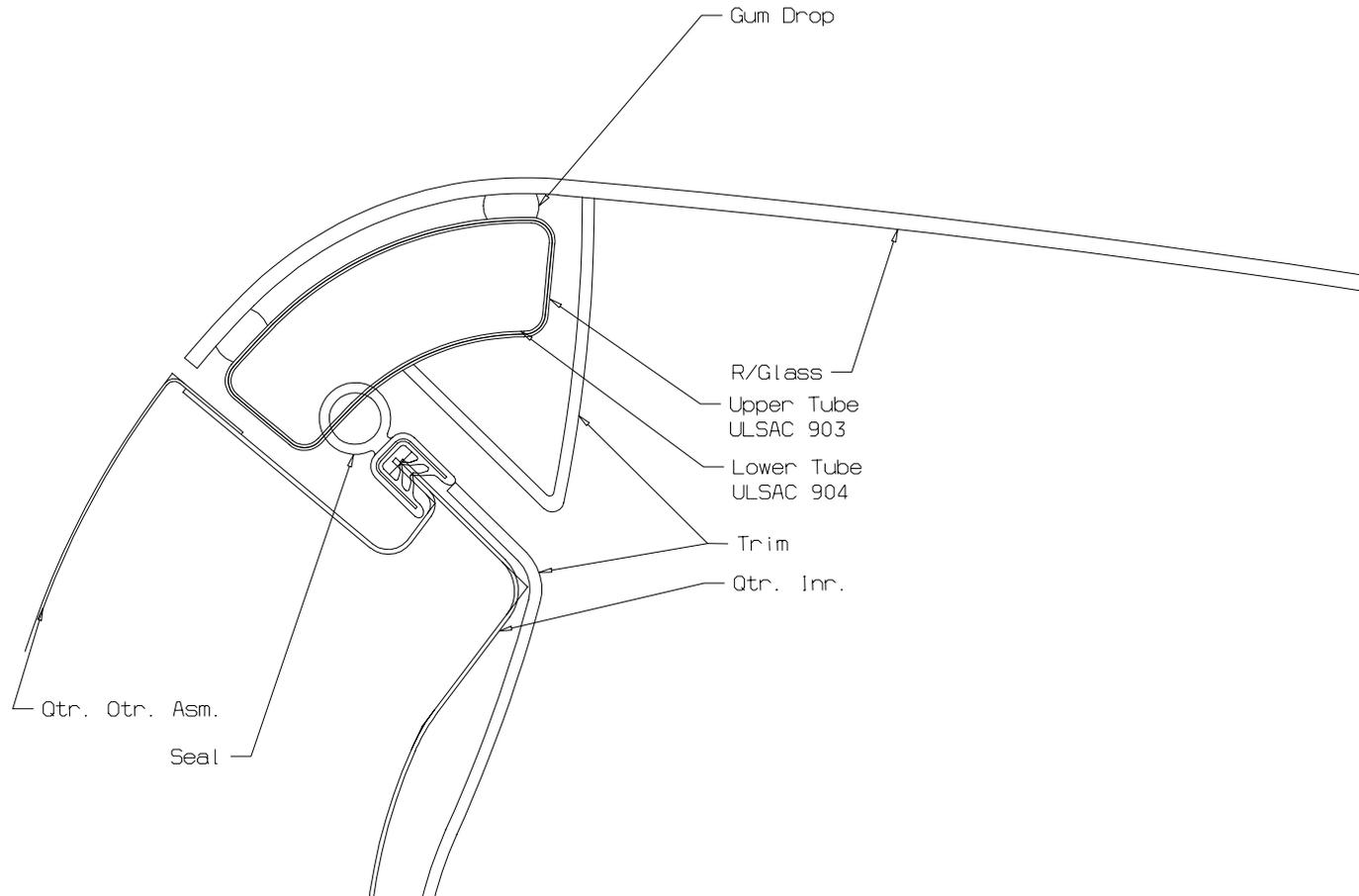




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Hydroformed Ring - Typical Sections**

### **Section C9**

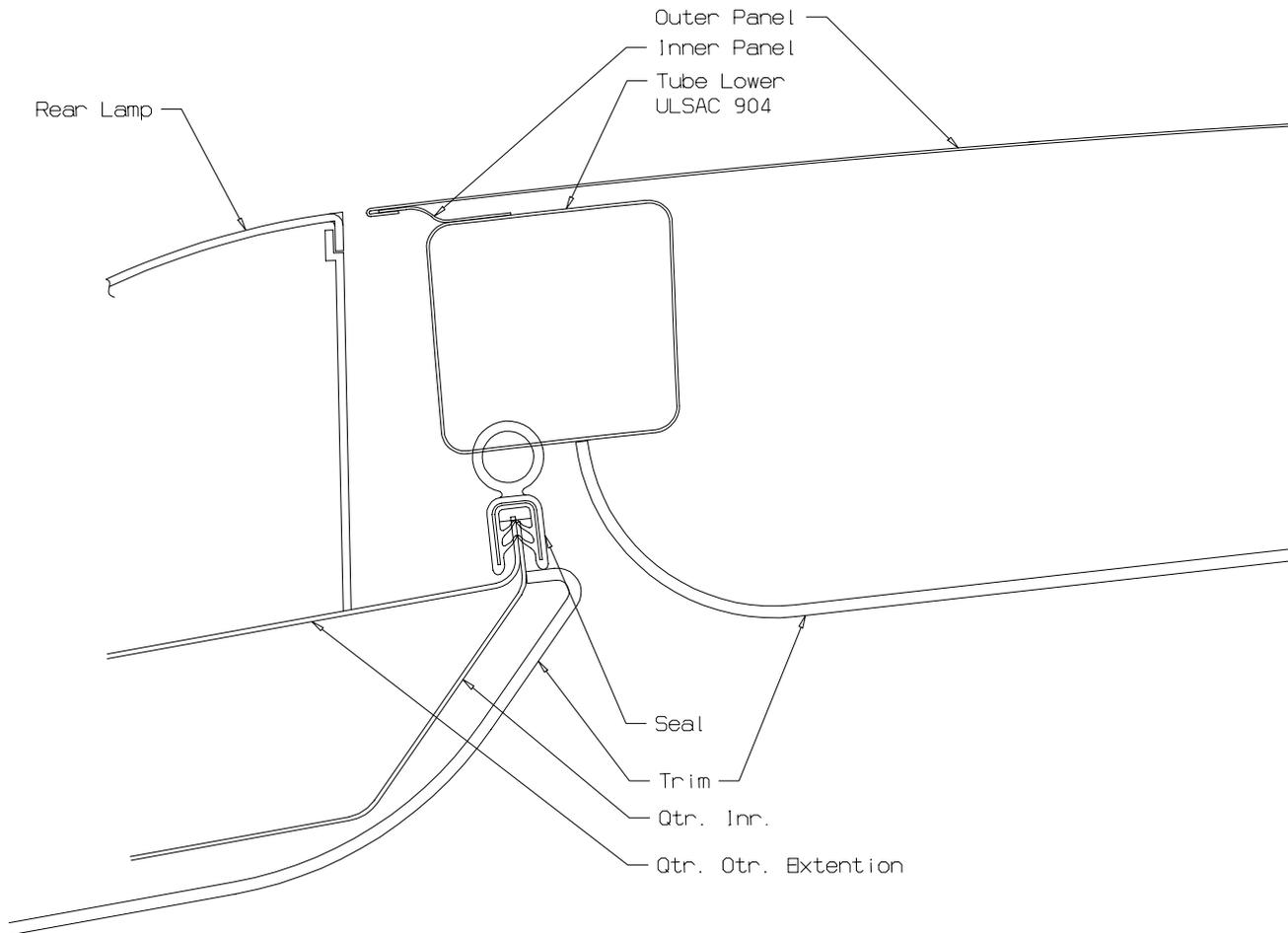




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Hydroformed Ring - Typical Sections**

### **Section D9**

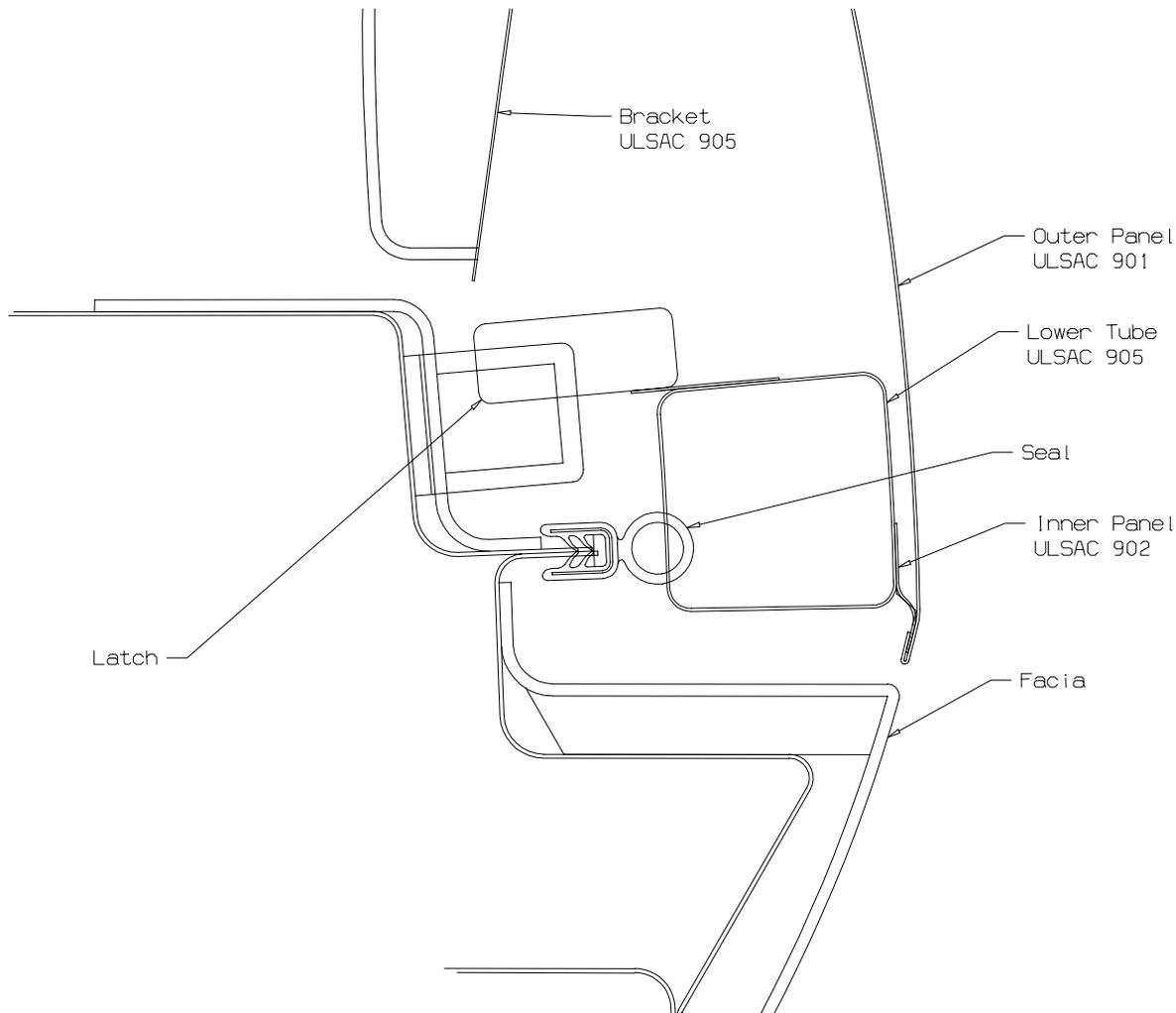




# Conceptual Design

## **Selected Design Concepts - Hatchbacks Hydroformed Ring - Typical Sections**

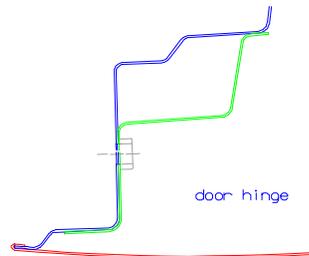
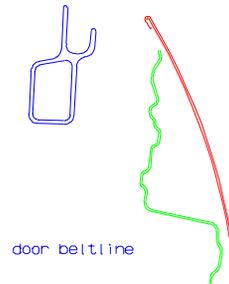
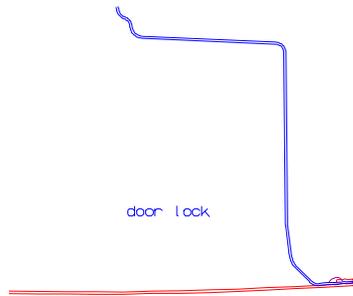
### **Section E9**





# Benchmarking

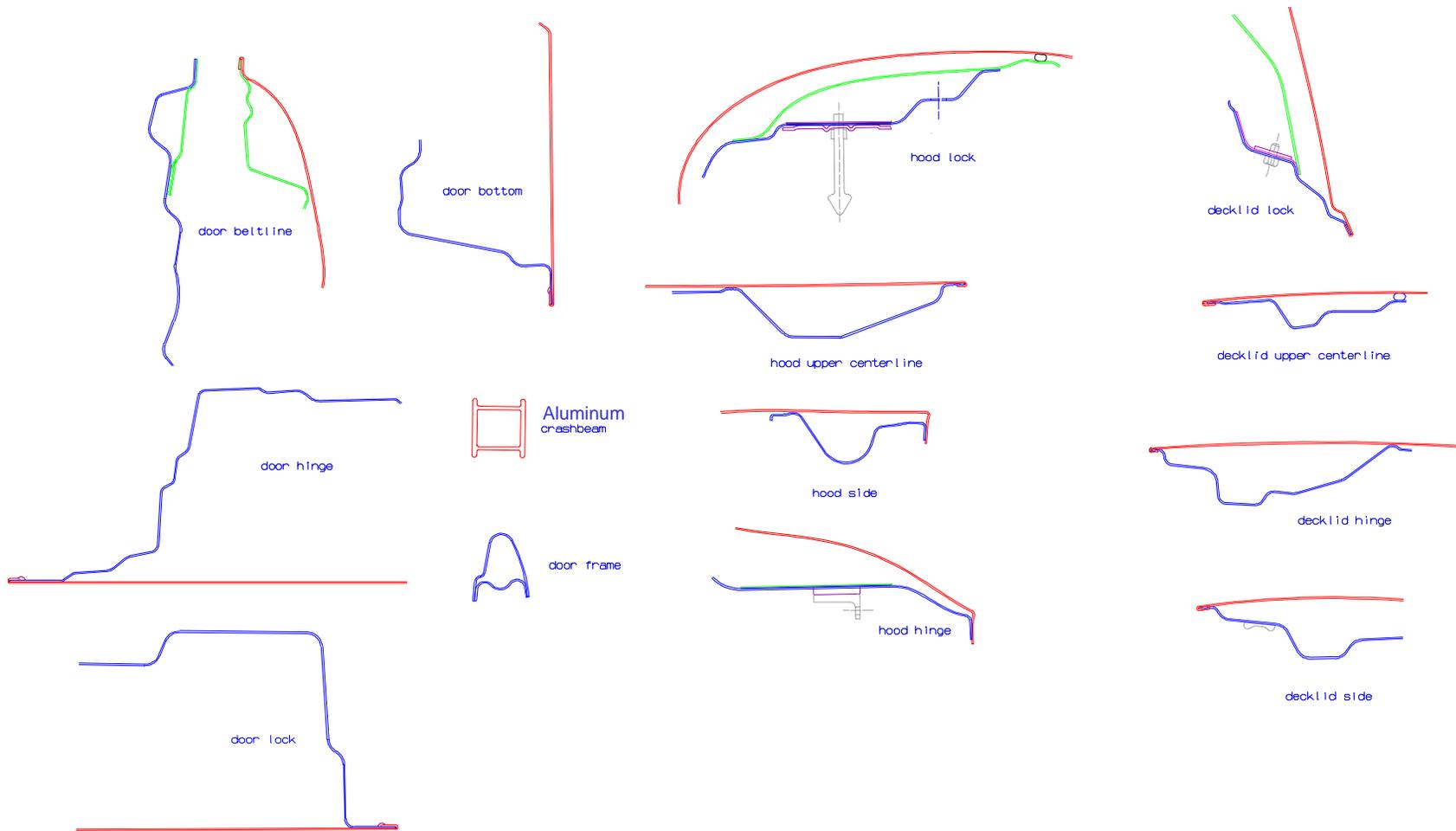
## **Typical Sections - Audi A6**





# Benchmarking

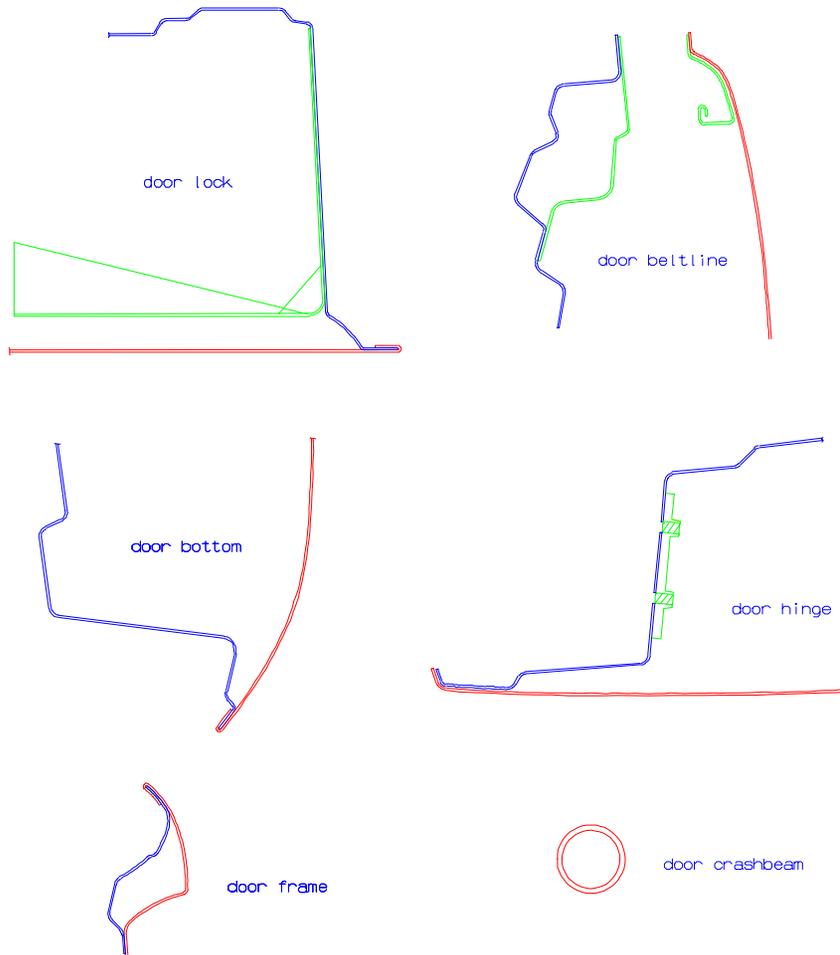
## Typical Sections - BMW 528i





# Benchmarking

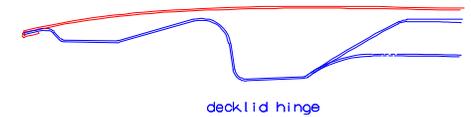
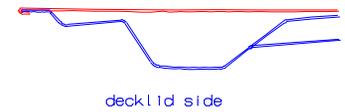
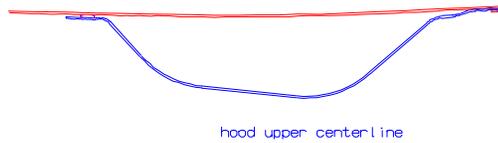
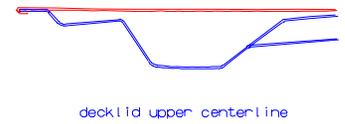
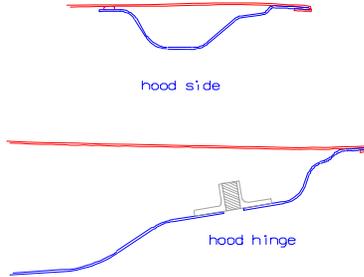
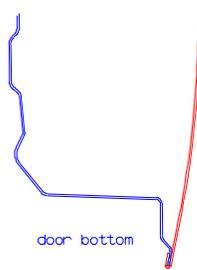
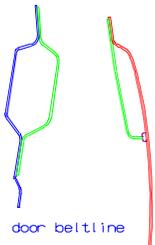
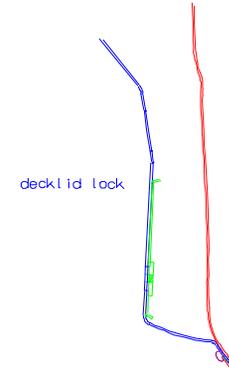
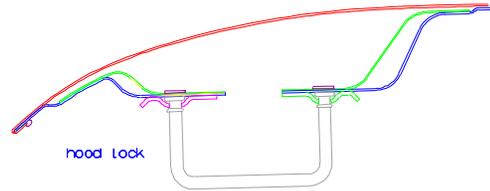
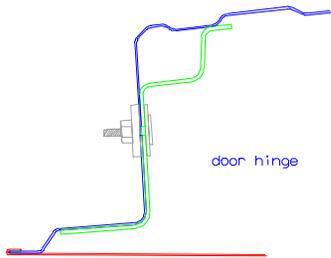
## *Typical Sections - Cadillac Sedan Deville*





# Benchmarking

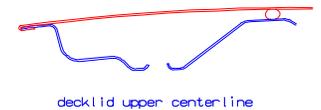
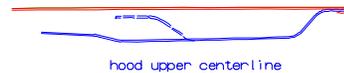
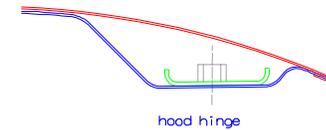
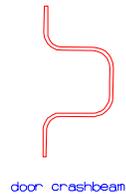
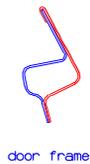
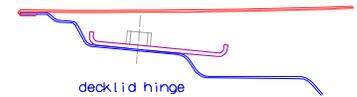
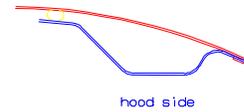
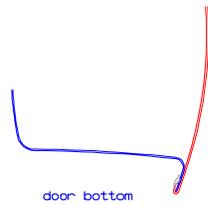
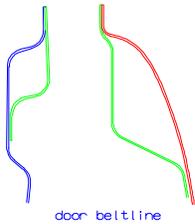
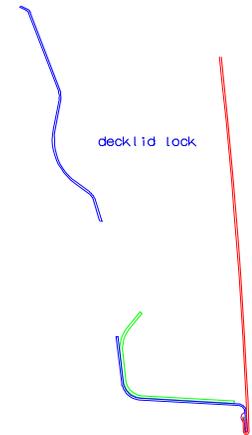
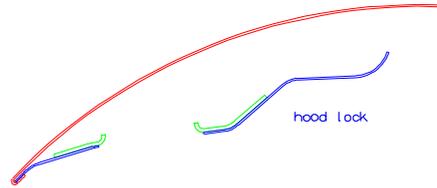
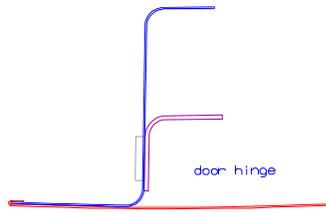
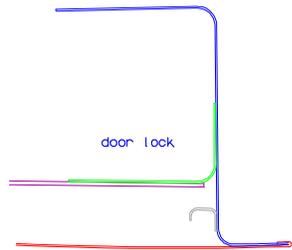
## Typical Sections - Chevrolet Malibu





# Benchmarking

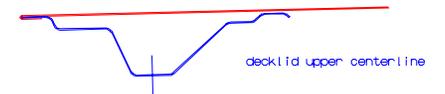
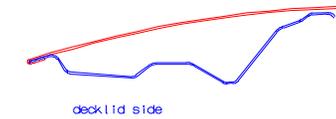
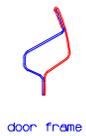
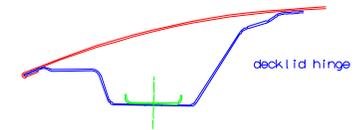
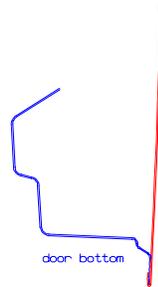
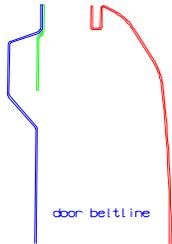
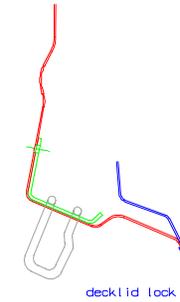
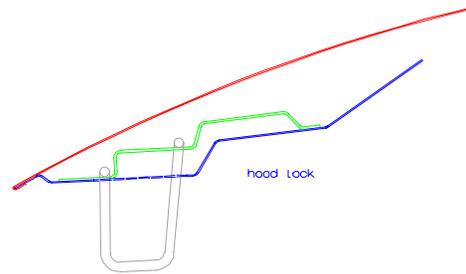
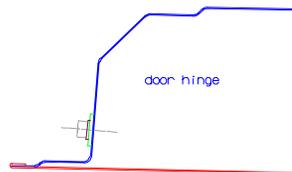
## Typical Sections - Dodge Stratus





# Benchmarking

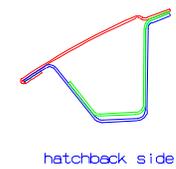
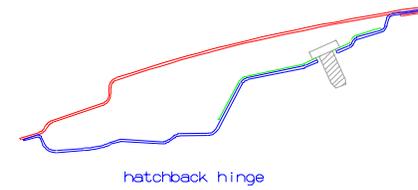
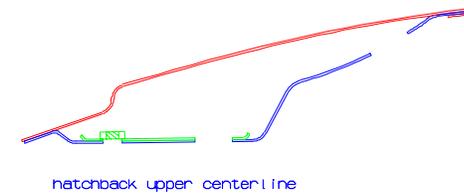
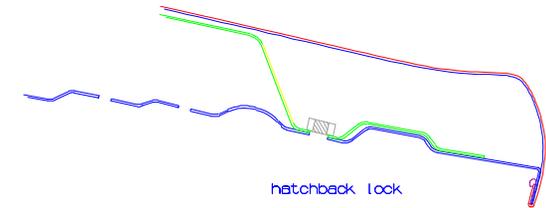
## *Typical Sections - Ford Contour*





# Benchmarking

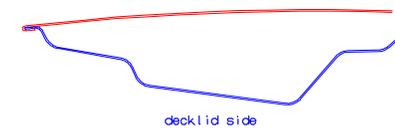
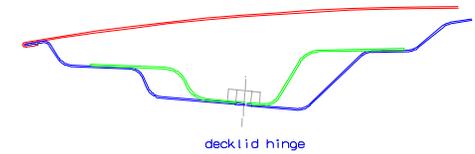
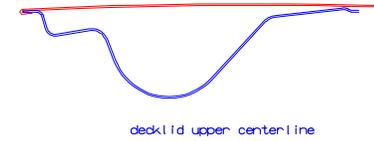
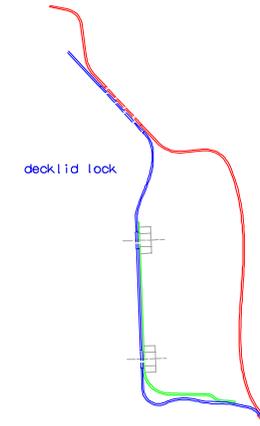
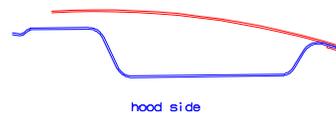
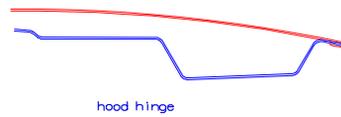
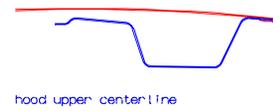
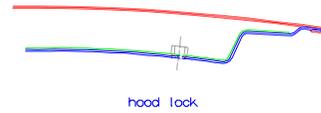
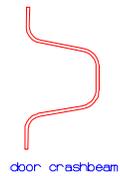
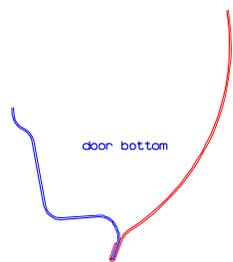
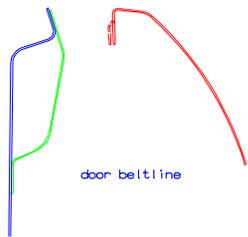
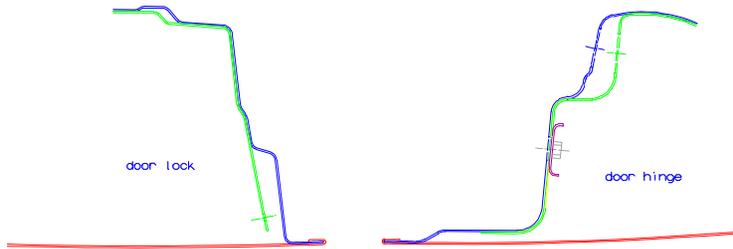
## *Typical Sections - Ford Probe*





# Benchmarking

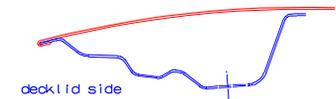
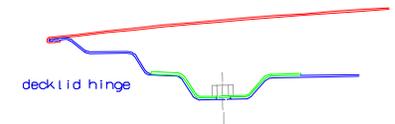
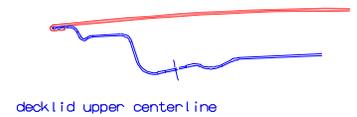
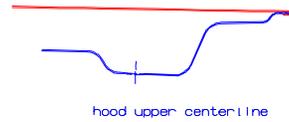
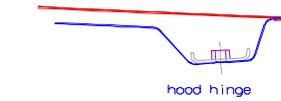
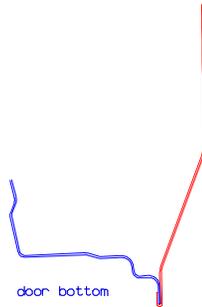
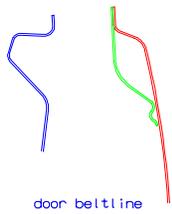
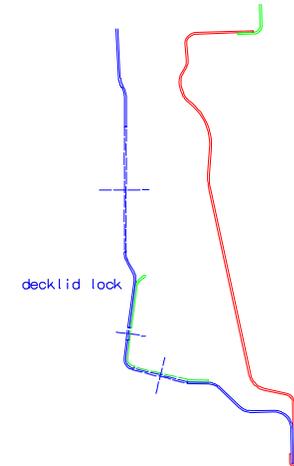
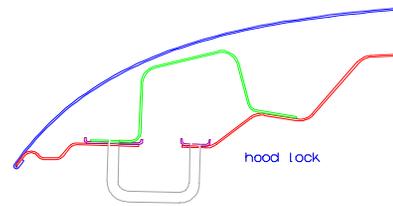
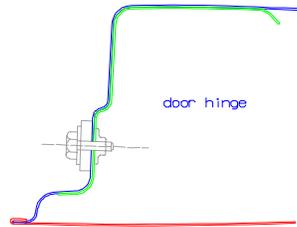
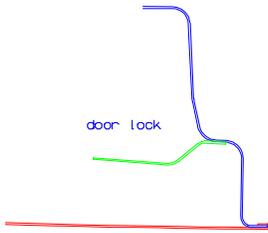
## *Typical Sections - Ford Taurus*





# Benchmarking

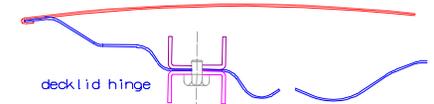
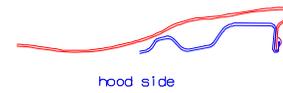
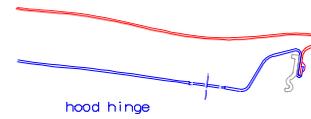
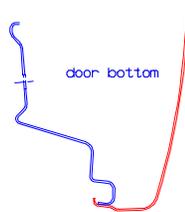
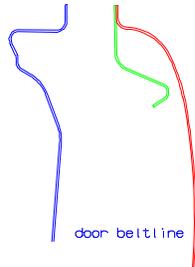
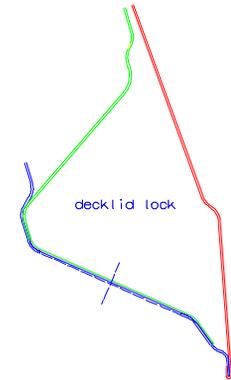
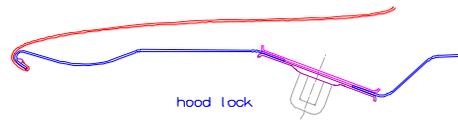
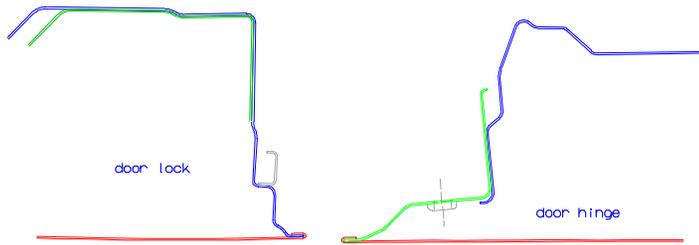
## *Typical Sections - Honda Accord*





# Benchmarking

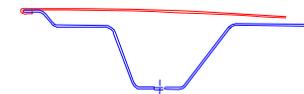
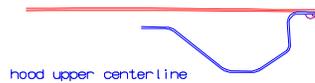
## Typical Sections - Mercedes E320



door frame



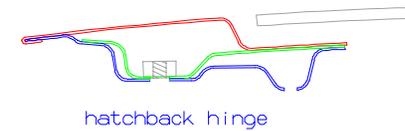
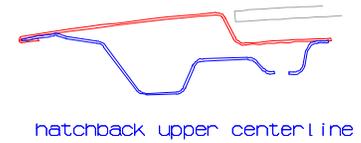
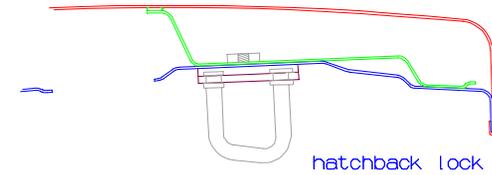
door crashbeam





# Benchmarking

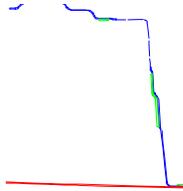
## *Typical Sections - Mitsubishi Eclipse*



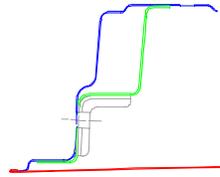


# Benchmarking

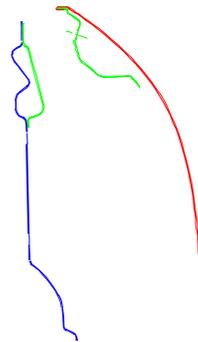
## *Typical Sections - Porsche Boxster*



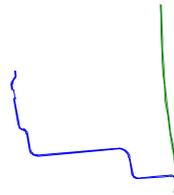
door lock



door hinge



door beltline



door bottom



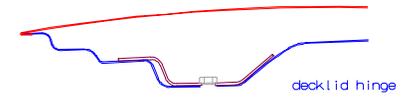
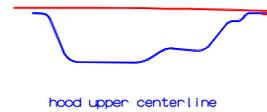
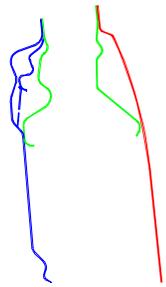
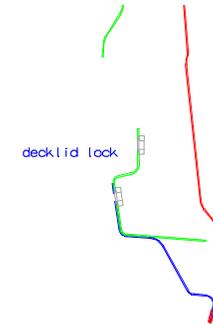
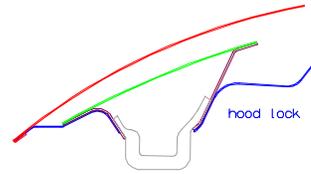
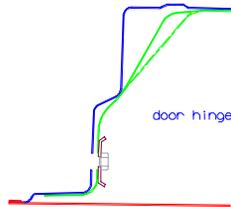
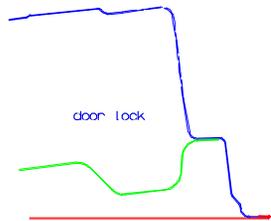
door crashbeam





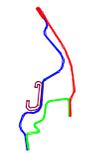
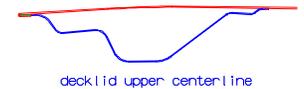
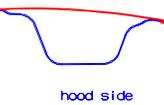
# Benchmarking

## *Typical Sections - Nissan Sentra*

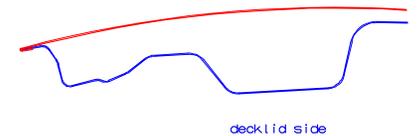
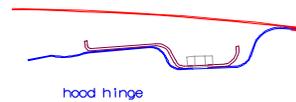


door beltline

door bottom



door crashbeam



door frame

hood hinge

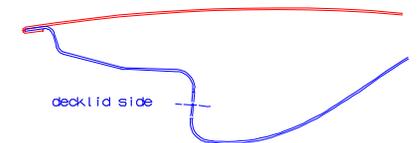
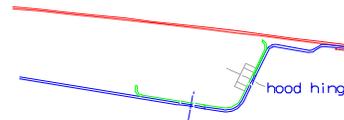
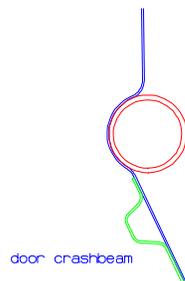
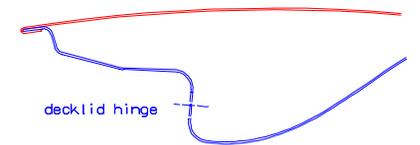
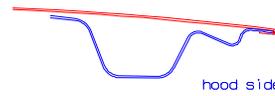
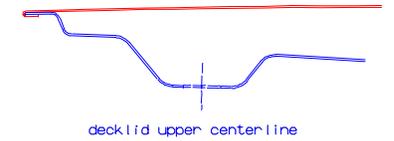
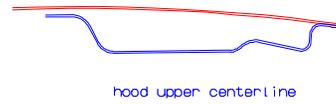
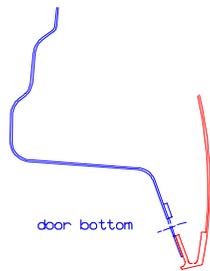
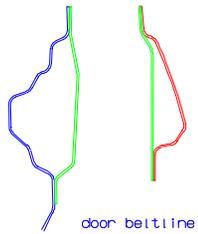
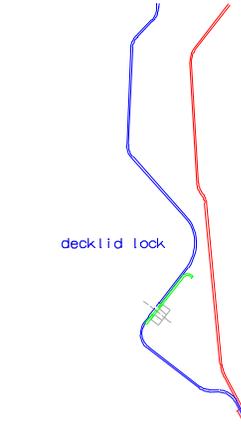
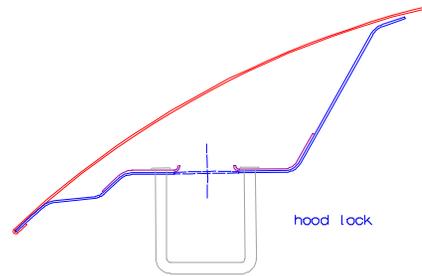
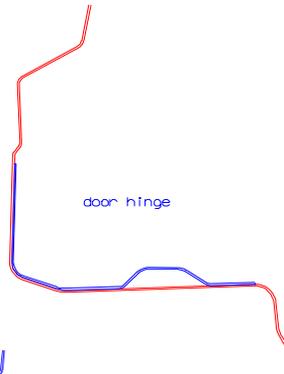
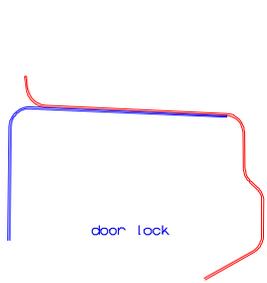
decklid side





# Benchmarking

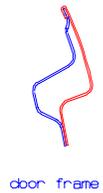
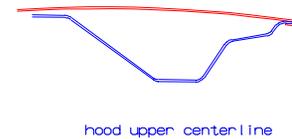
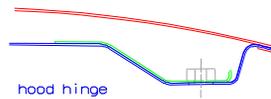
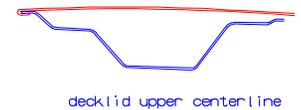
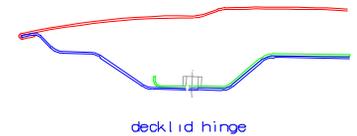
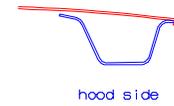
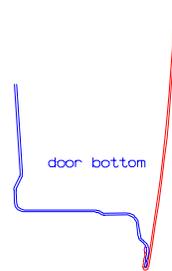
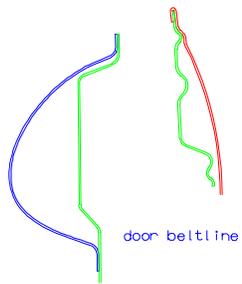
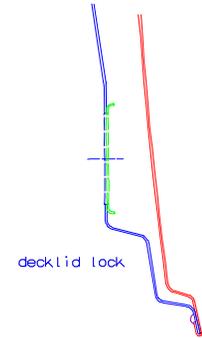
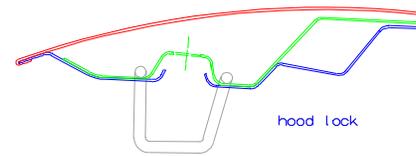
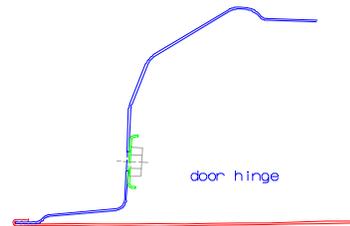
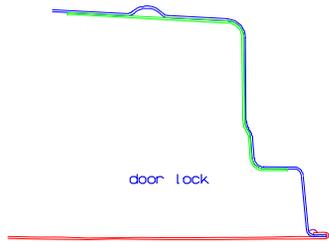
## Typical Sections - Saturn LS





# Benchmarking

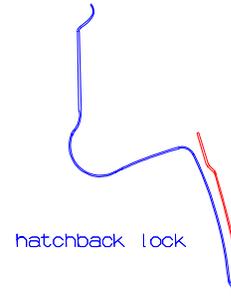
## Typical Sections - Toyota Camry



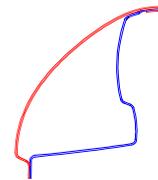


# Benchmarking

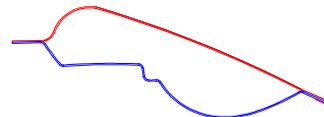
## *Typical Sections - VW Golf*



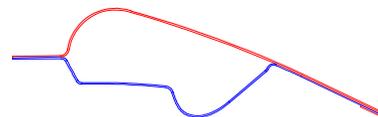
hatchback lock



hatchback side



hatchback upper centerline



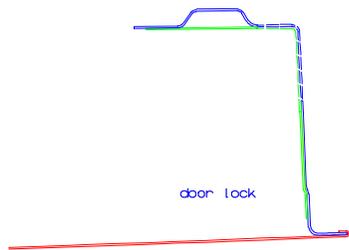
hatchback hinge



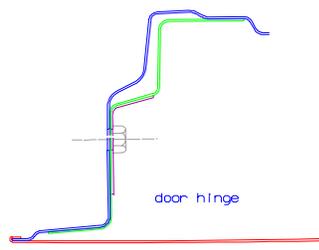


# Benchmarking

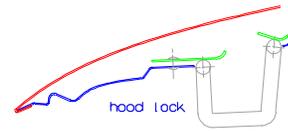
## Typical Sections - VW Passat



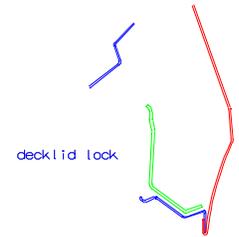
door lock



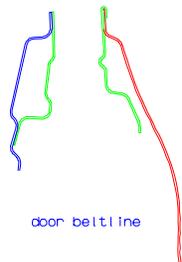
door hinge



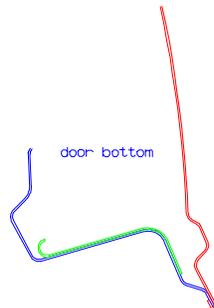
hood lock



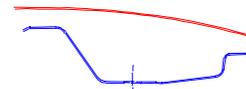
decklid lock



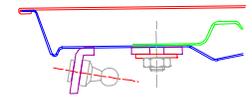
door beltline



door bottom



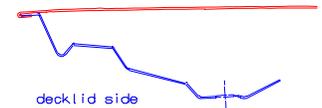
hood side



decklid hinge



hood upper centerline



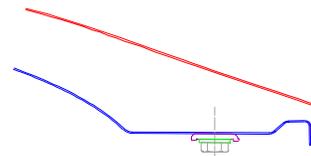
decklid side



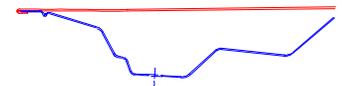
door frame



door crashbeam



hood hinge



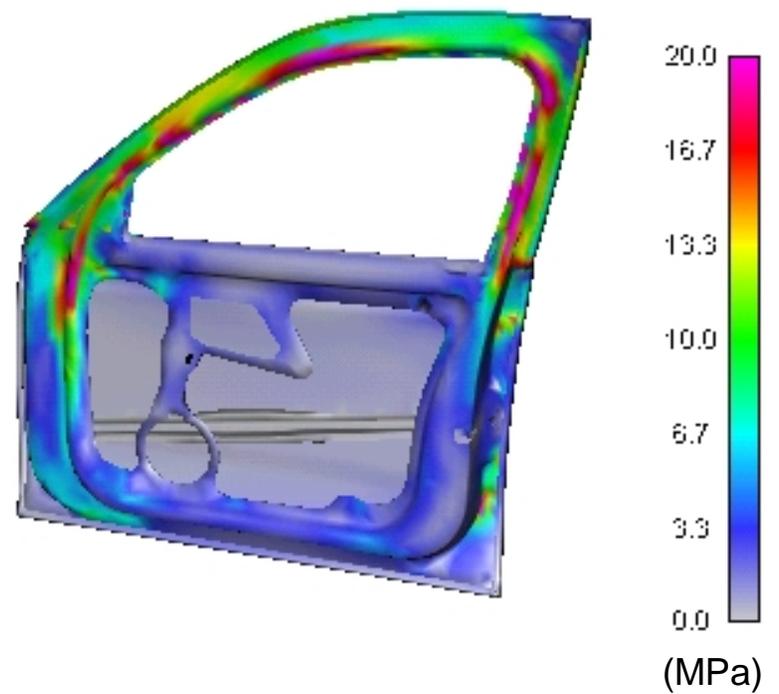
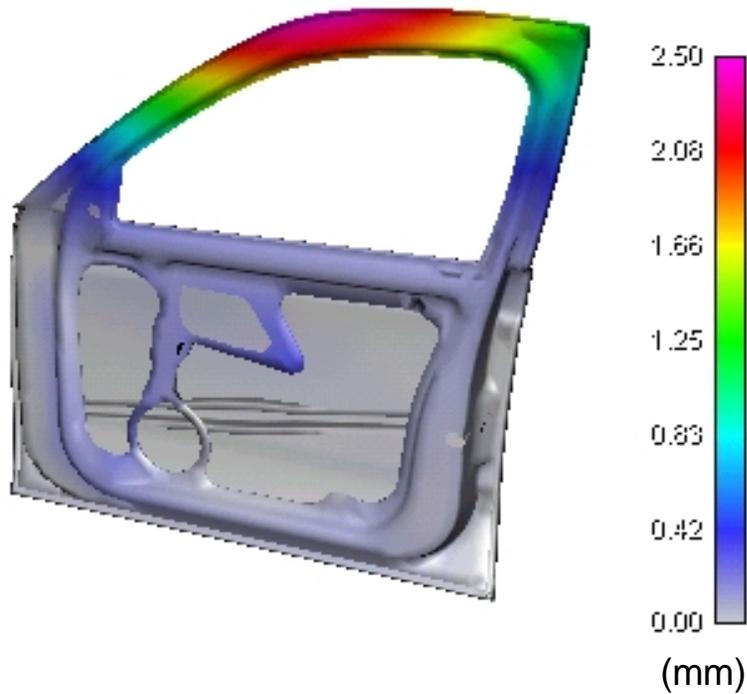
decklid upper centerline





# FEA Calculation

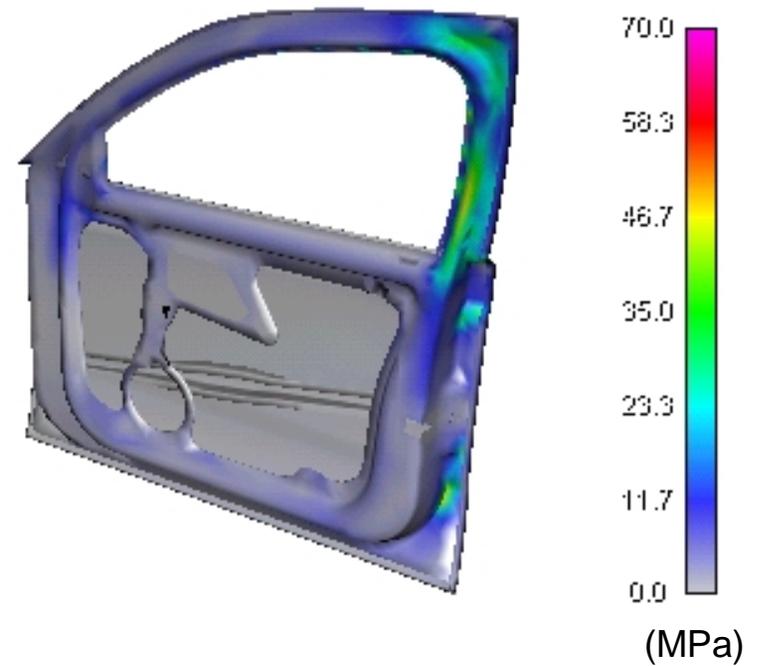
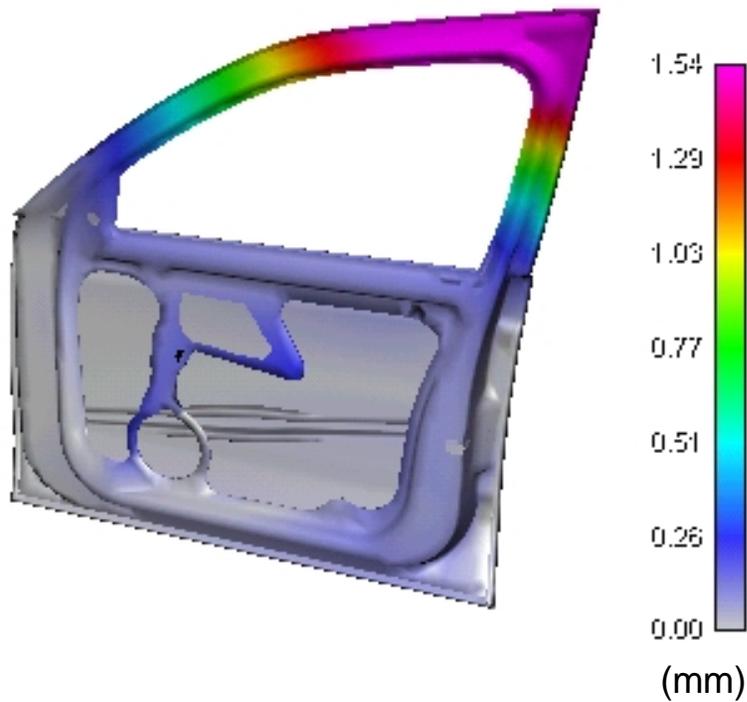
## *Results - Door - Roof Integrated Frame Rigidity Front - Deformation & Stress Plots*





# FEA Calculation

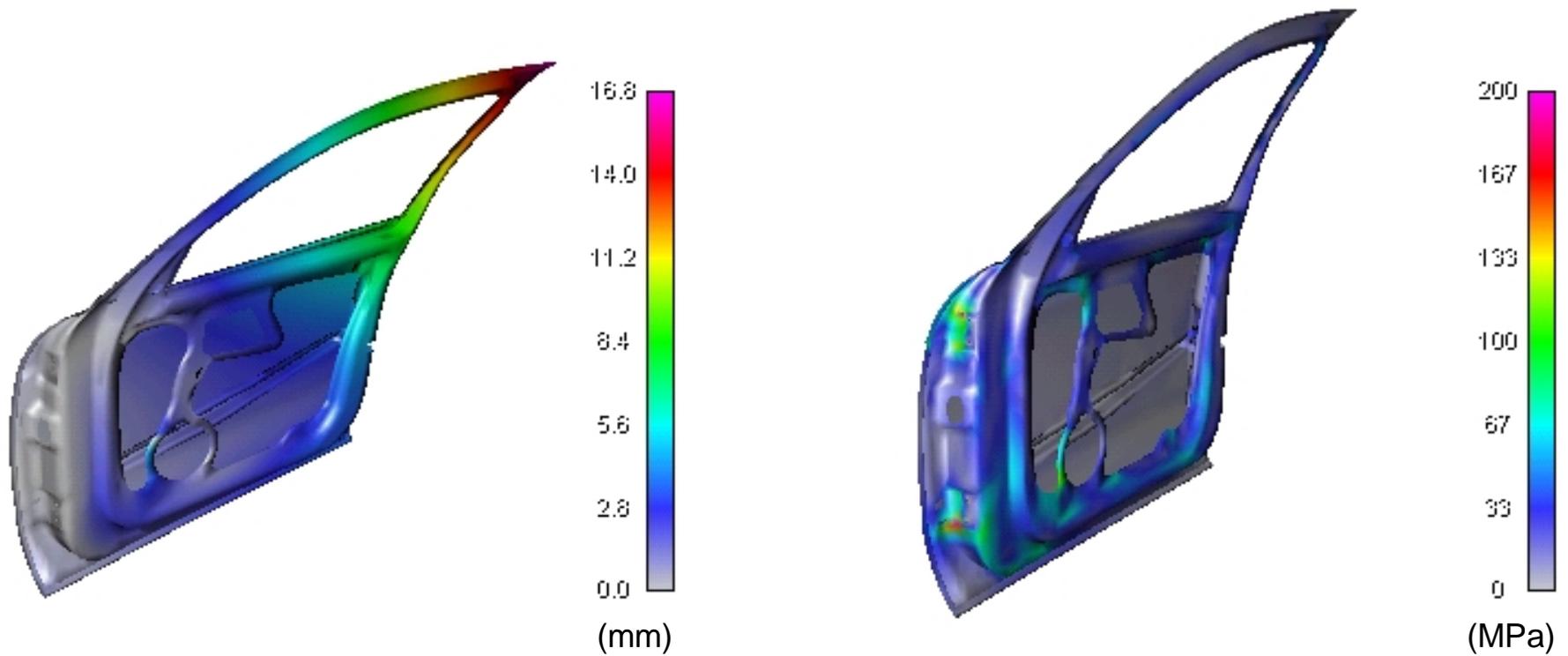
## *Results - Door - Roof Integrated Frame Rigidity Rear - Deformation & Stress Plots*





# FEA Calculation

## *Results - Door - Roof Integrated Door Sag - Deformation & Stress Plots*

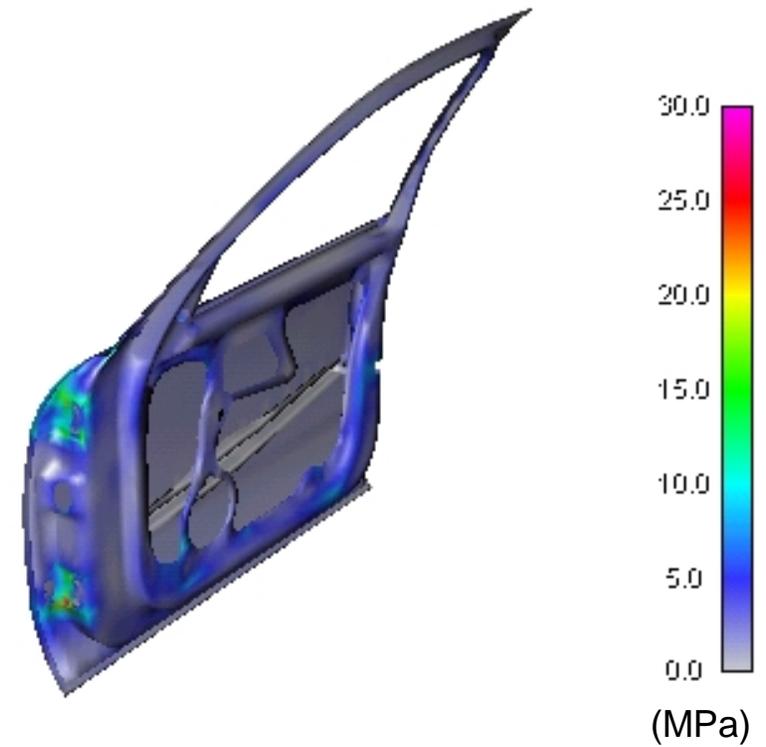
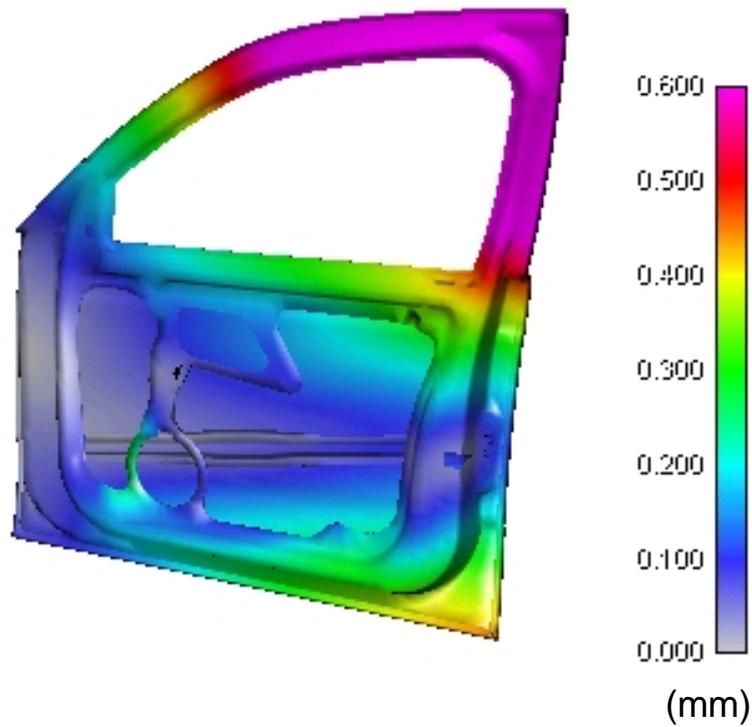




# FEA Calculation

**Results - Door - Roof Integrated**

**Torsional Rigidity Upper - Deformation & Stress Plots**

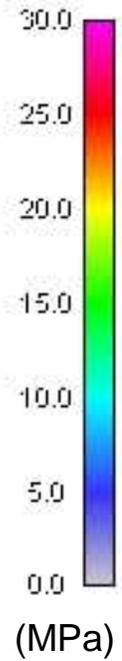
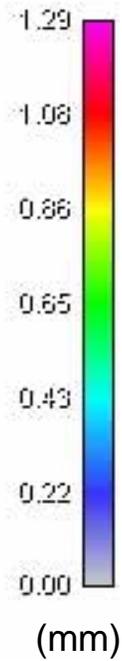
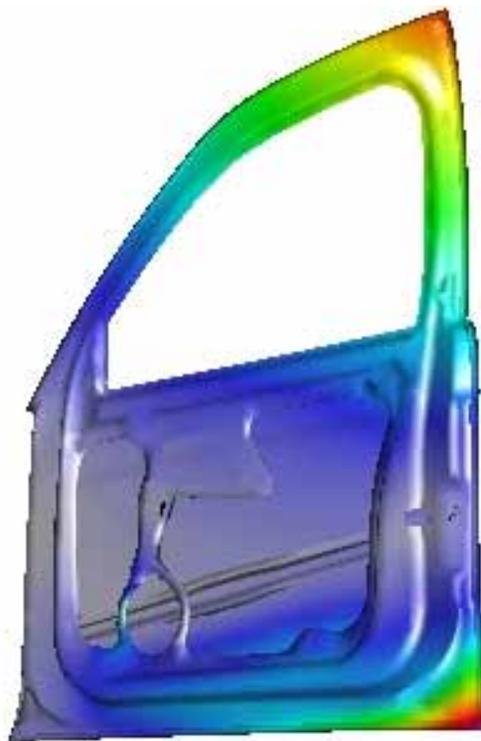




# FEA Calculation

**Results - Door - Roof Integrated**

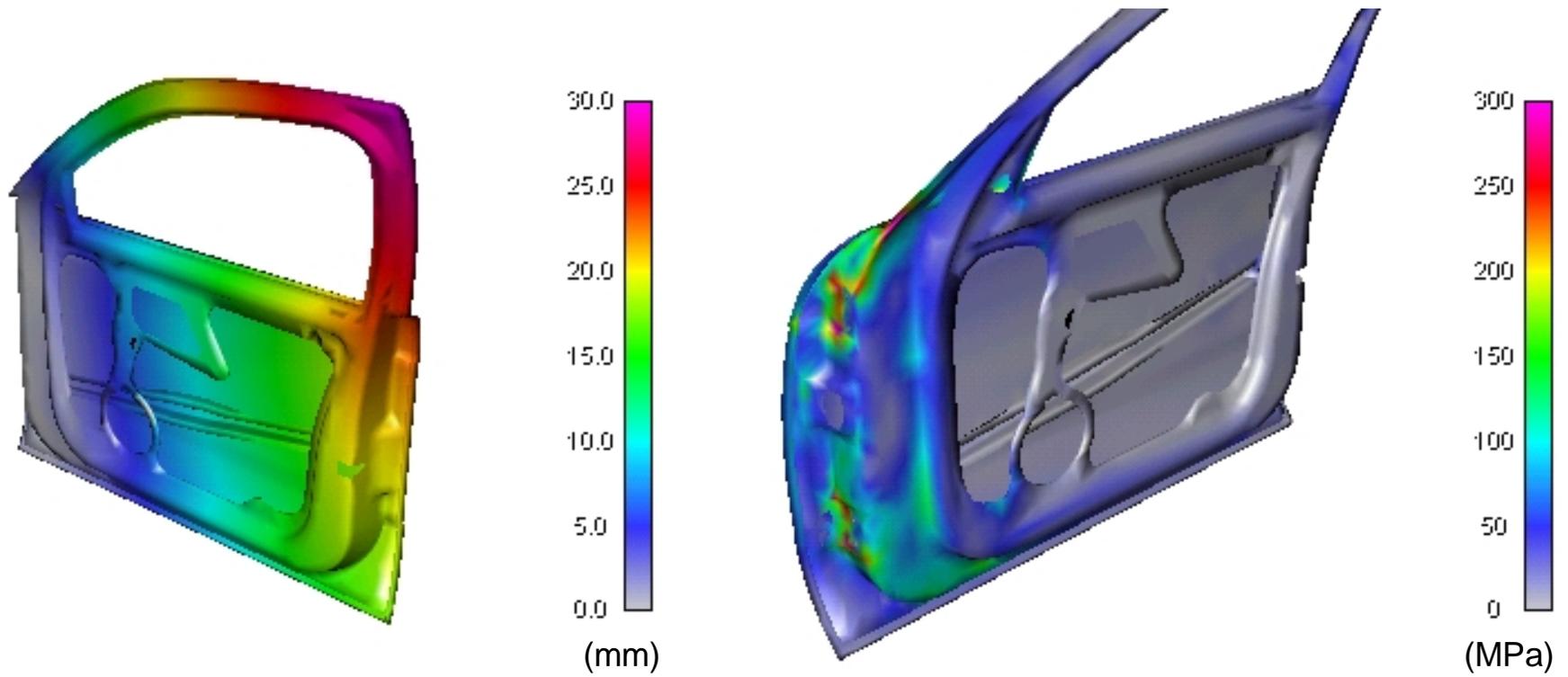
**Torsional Rigidity Lower - Deformation & Stress Plots**





# FEA Calculation

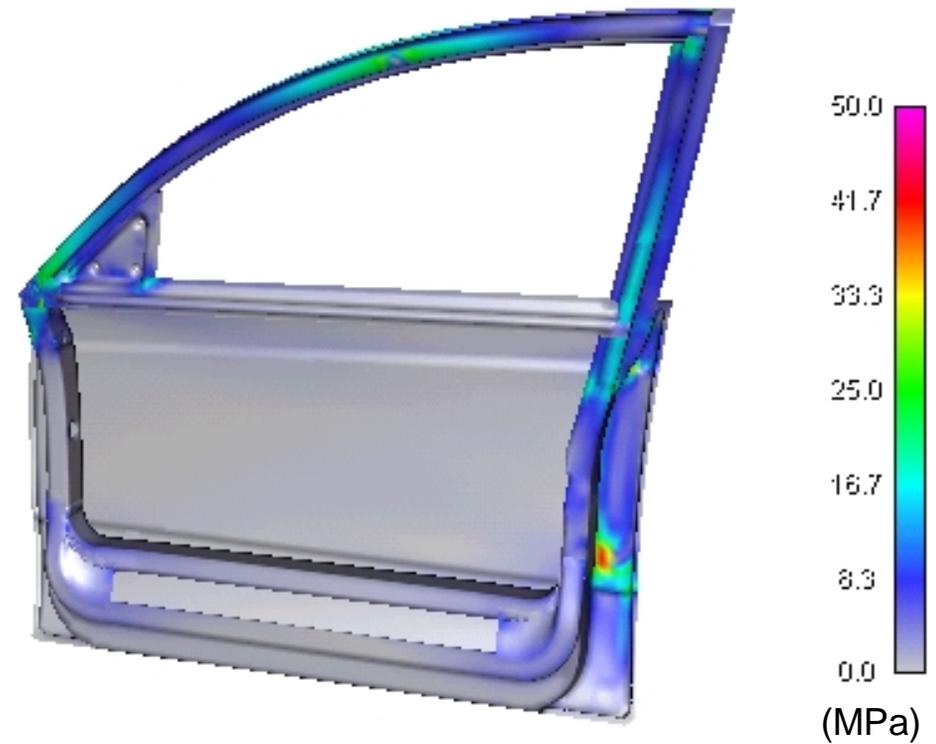
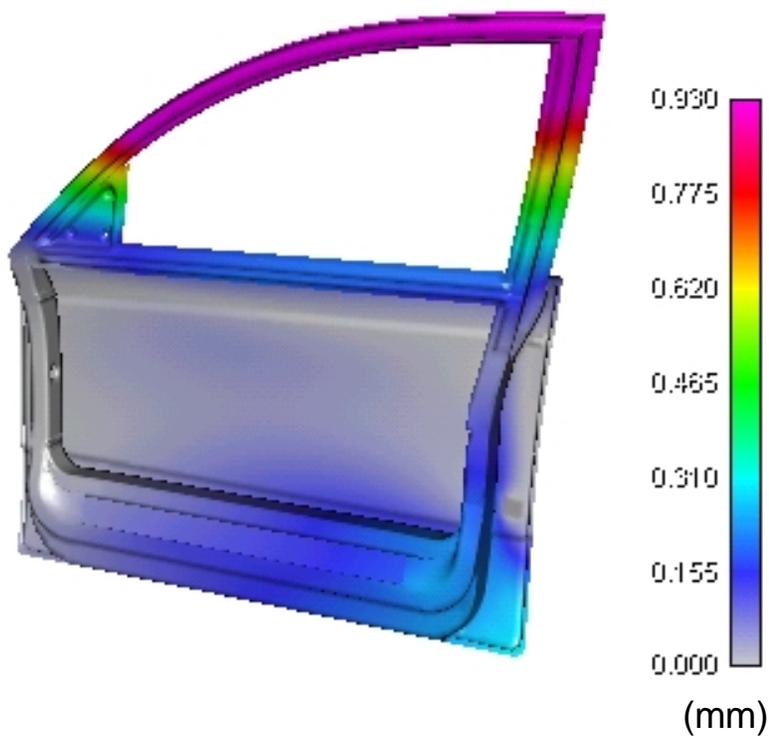
## *Results - Door - Roof Integrated Checkload - Deformation & Stress Plots*





# FEA Calculation

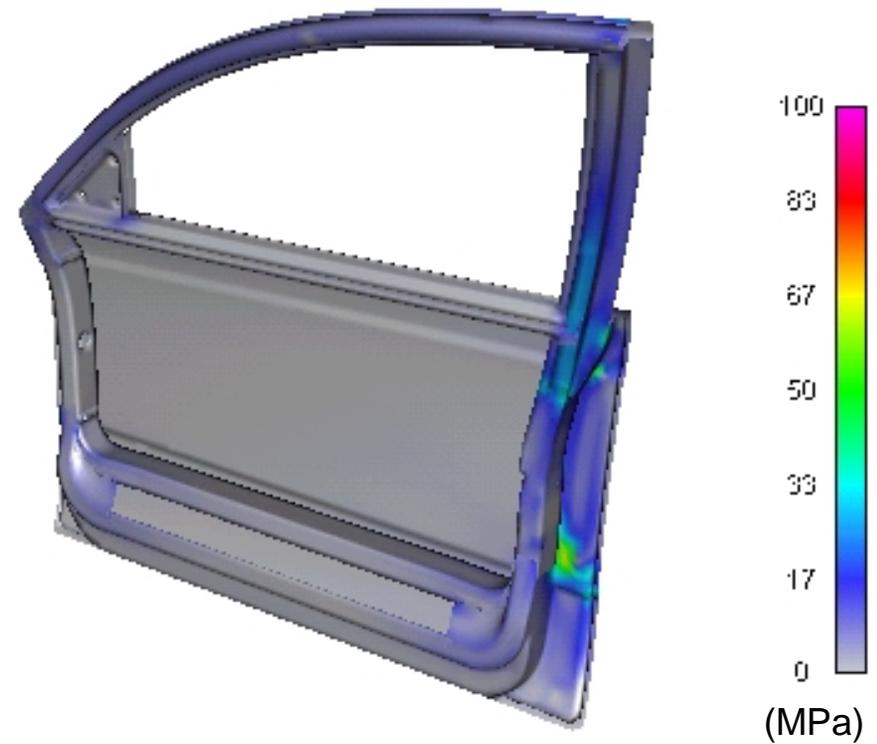
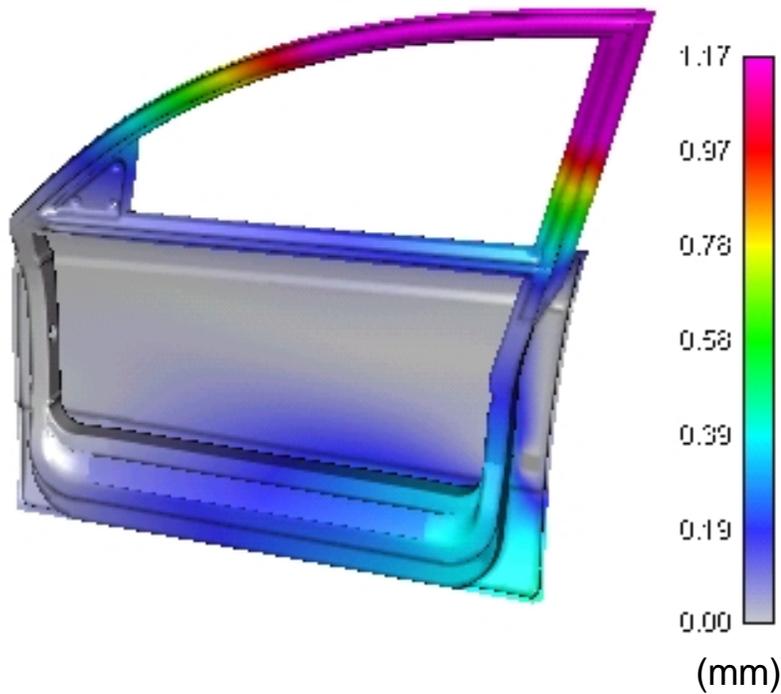
## *Results - Door - Frame Integrated Frame Rigidity Front - Deformation & Stress Plots*





# FEA Calculation

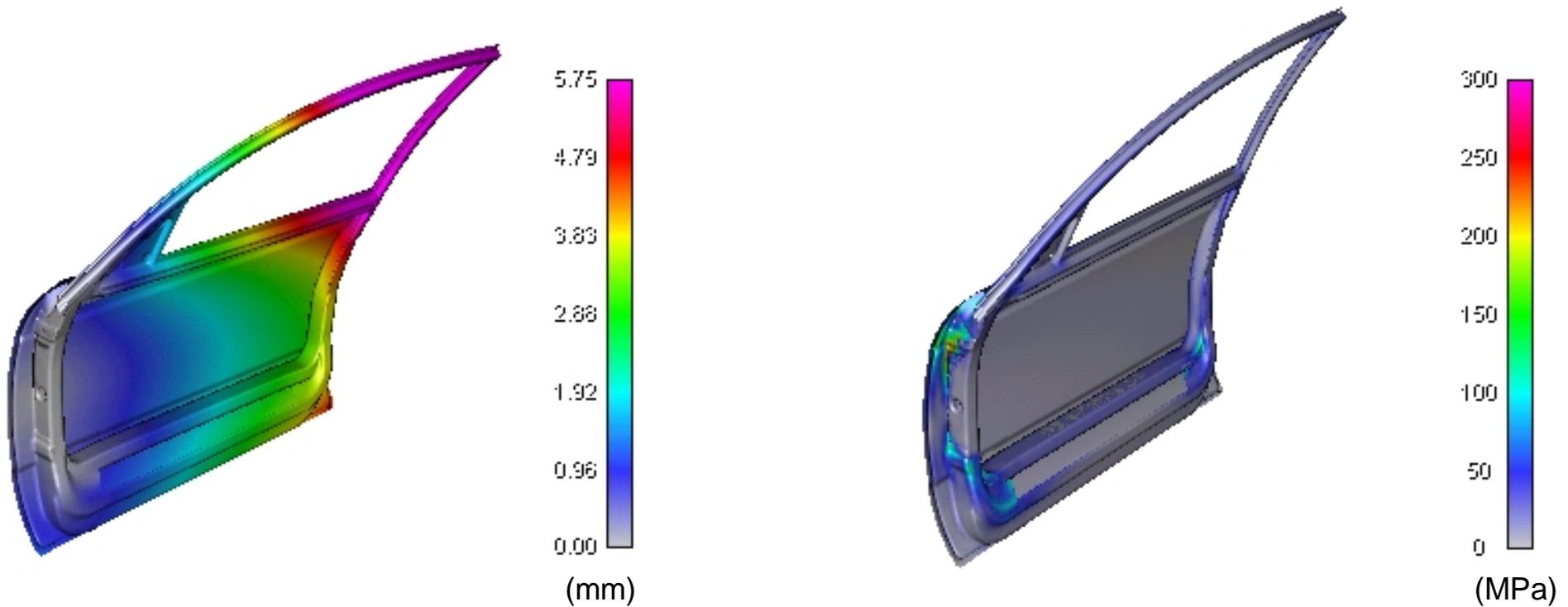
## *Results - Door - Frame Integrated Frame Rigidity Rear - Deformation & Stress Plots*





## FEA Calculation

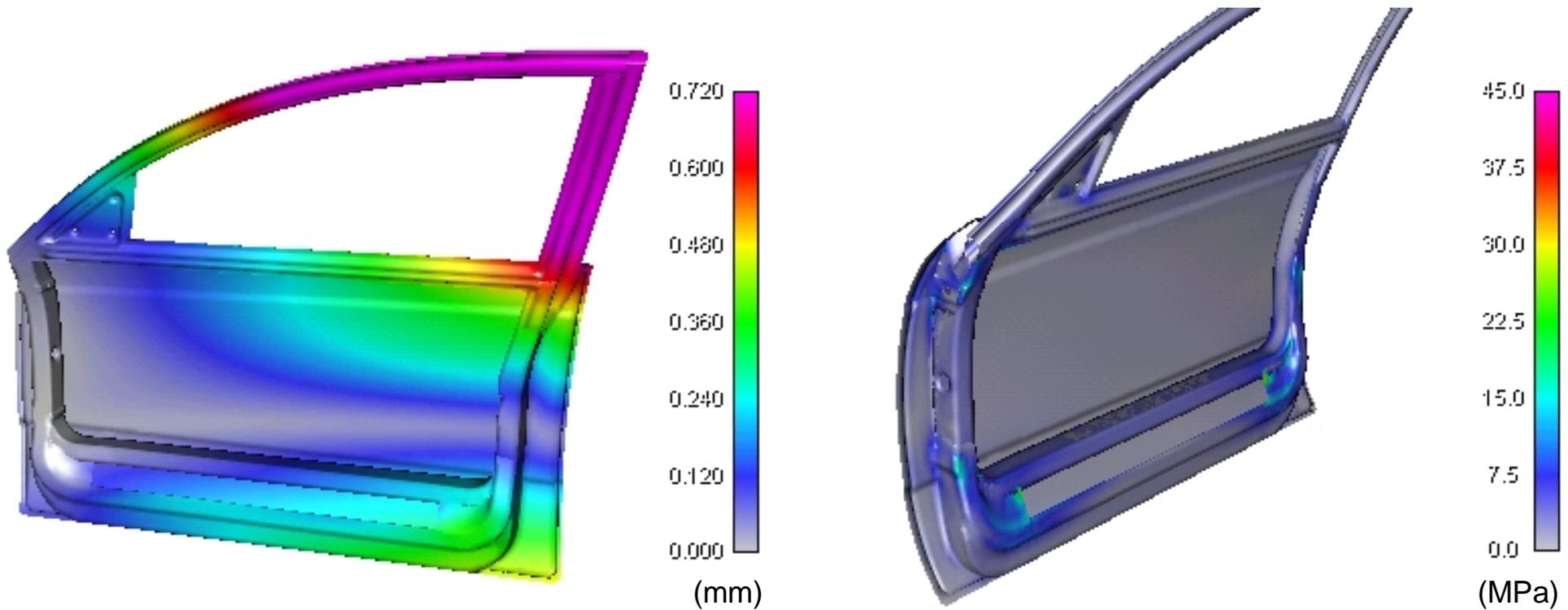
### *Results - Door - Frame Integrated Door Sag - Deformation & Stress Plots*





# FEA Calculation

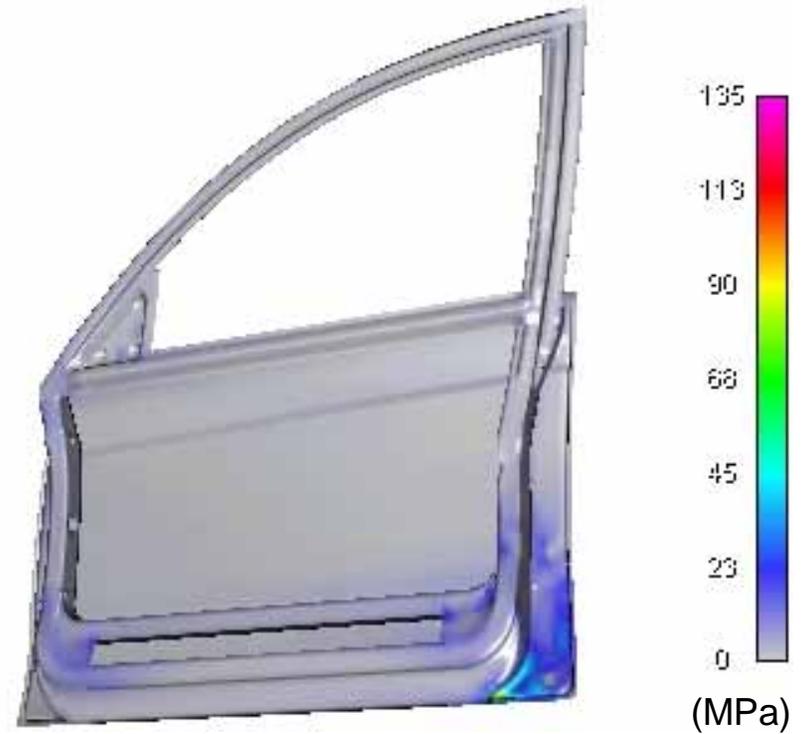
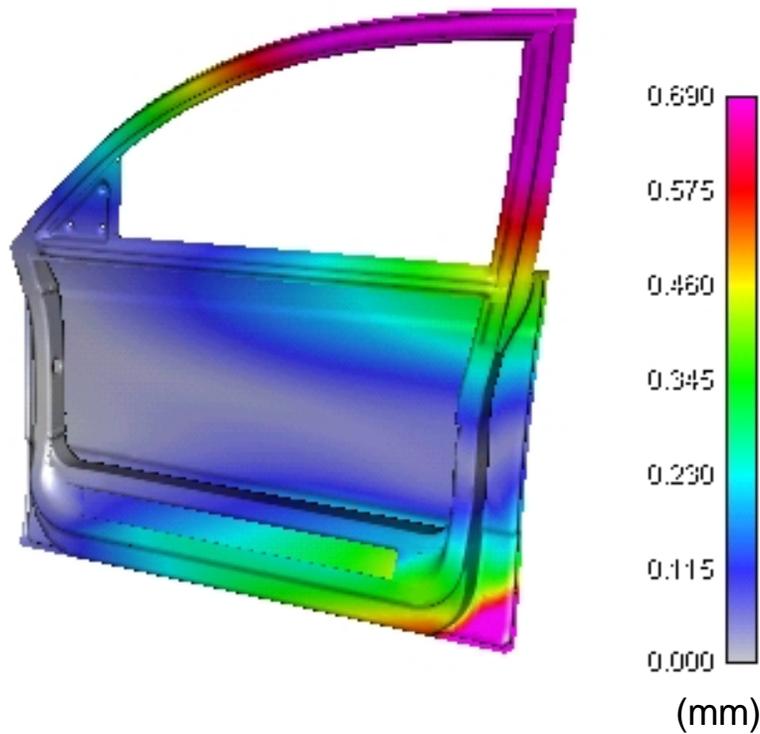
## *Results - Door - Frame Integrated Torsional Rigidity Upper - Deformation & Stress Plots*





# FEA Calculation

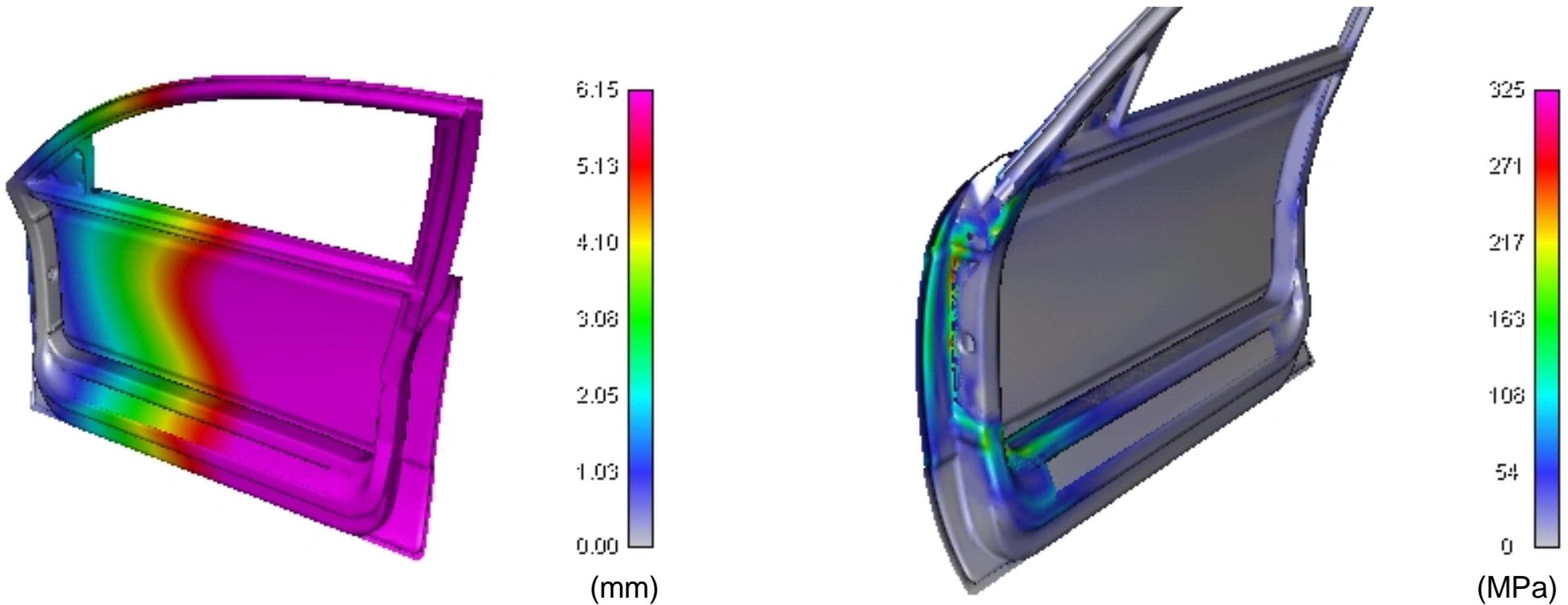
**Results - Door - Frame Integrated**  
**Torsional Rigidity Lower - Deformation & Stress Plots**





# FEA Calculation

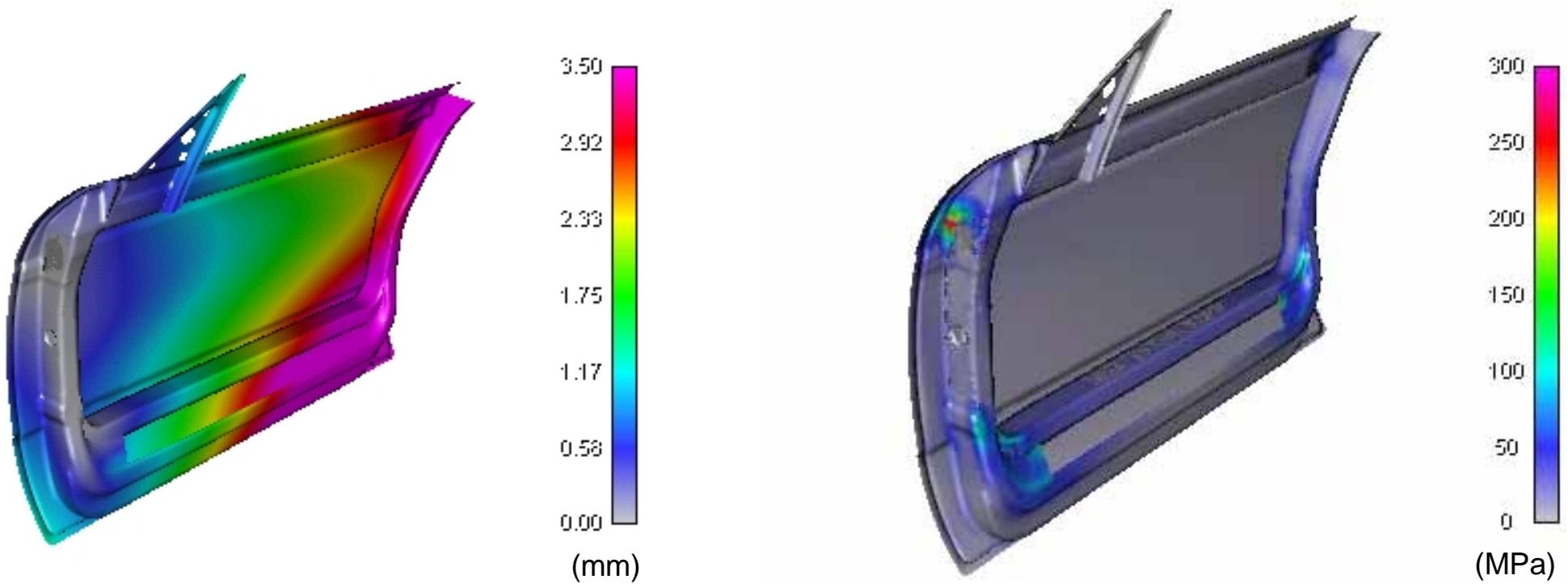
## *Results - Door - Frame Integrated Checkload - Deformation & Stress Plots*





# FEA Calculation

## *Results - Door - Frameless Door Sag - Deformation & Stress Plots*

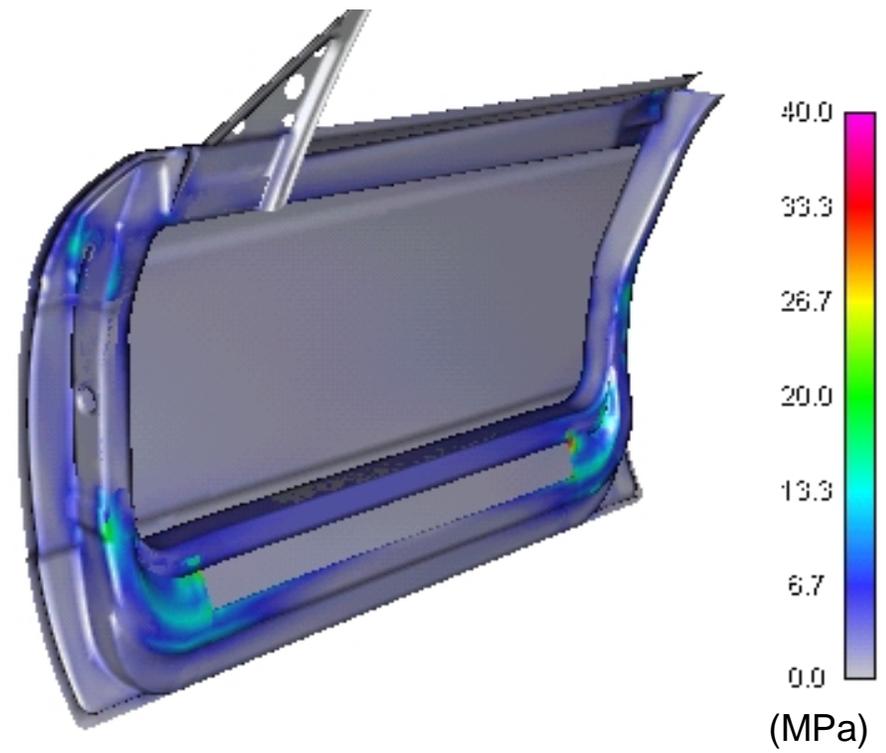
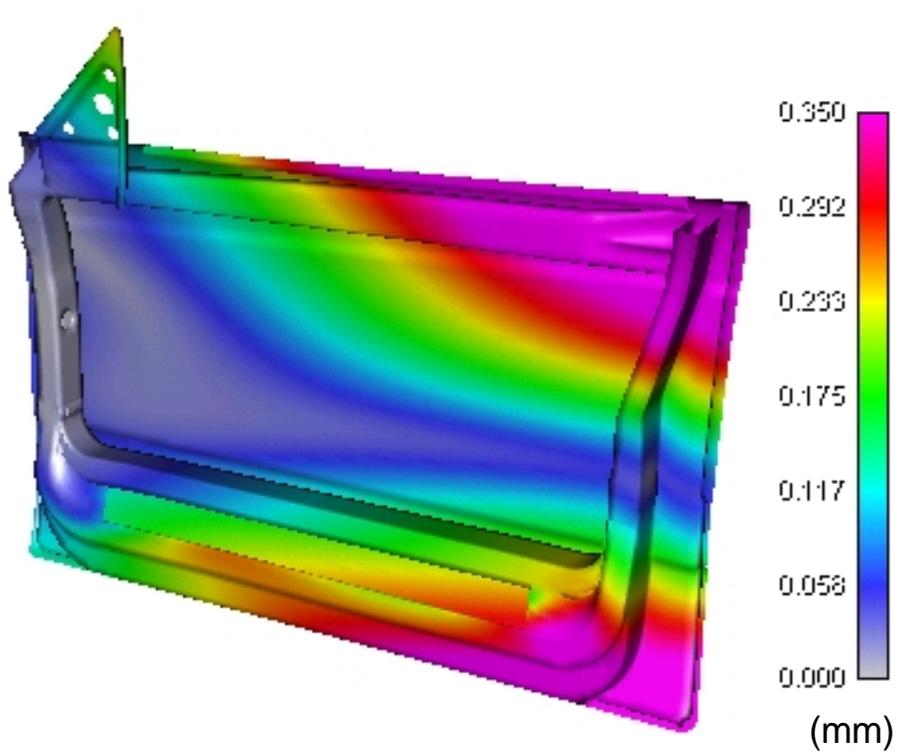




# FEA Calculation

## *Results - Door - Frameless*

### *Torsional Rigidity Upper - Deformation & Stress Plots*

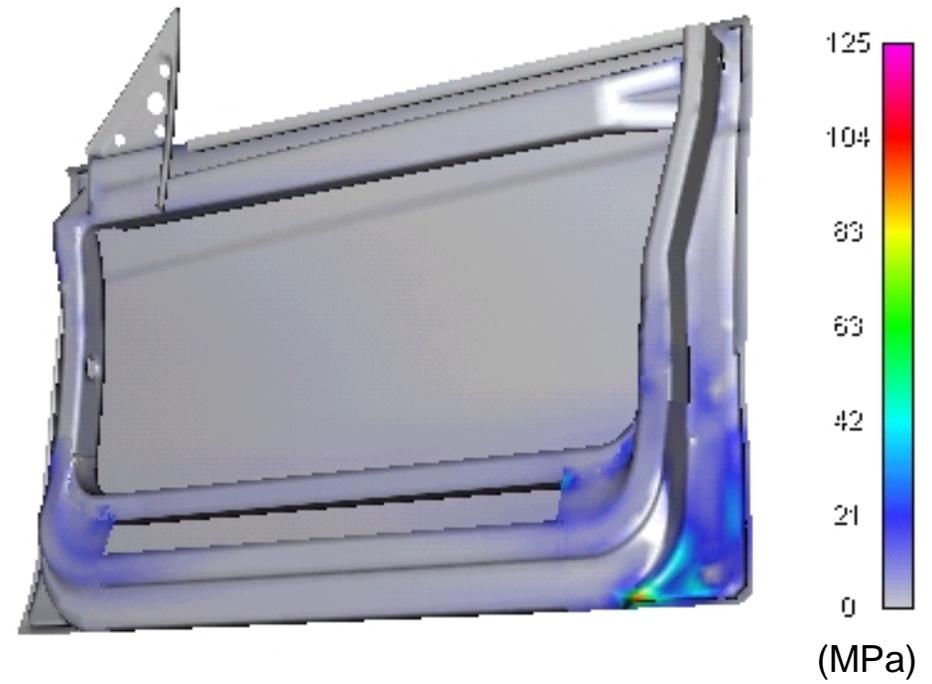
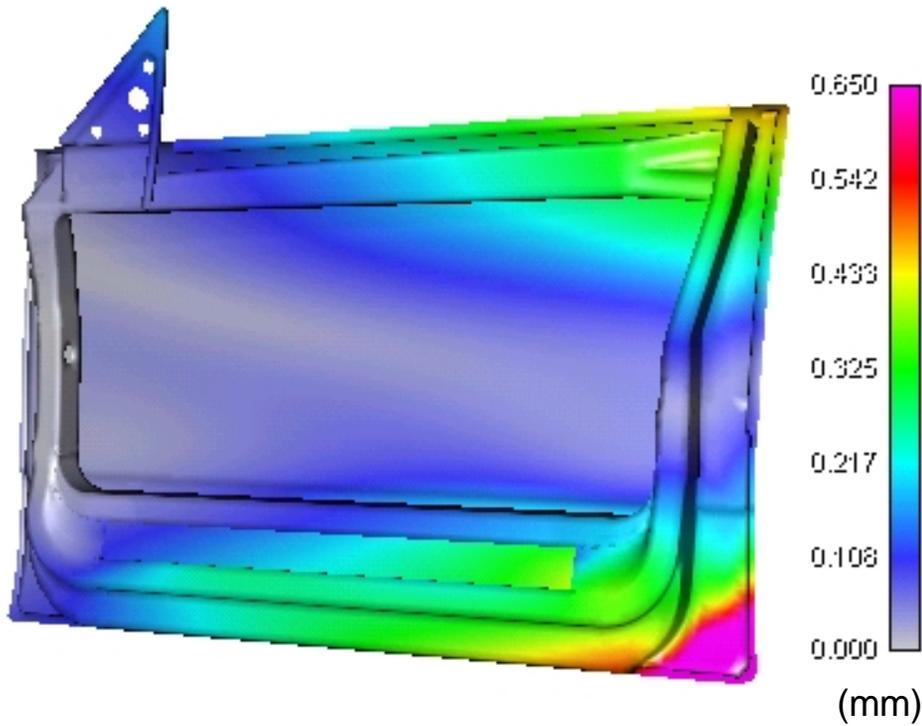




# FEA Calculation

**Results - Door - Frameless**

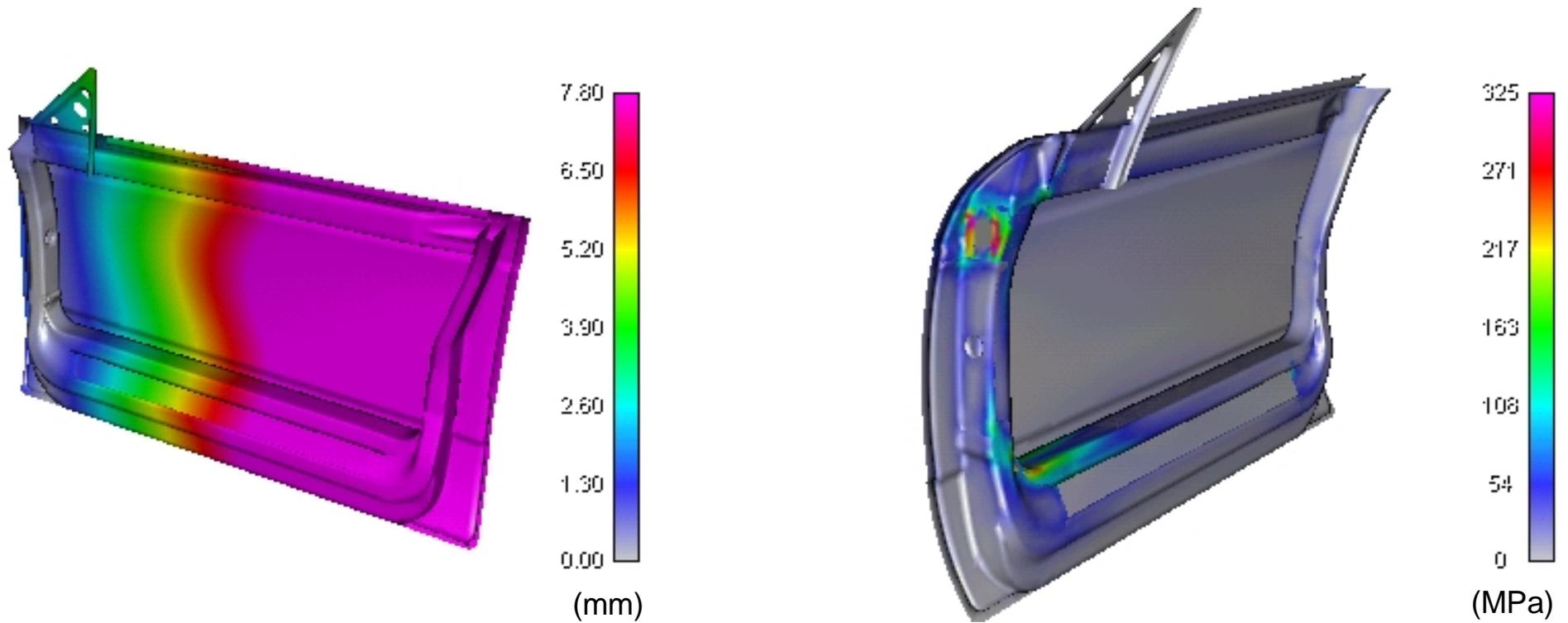
**Torsional Rigidity Lower - Deformation & Stress Plots**





# FEA Calculation

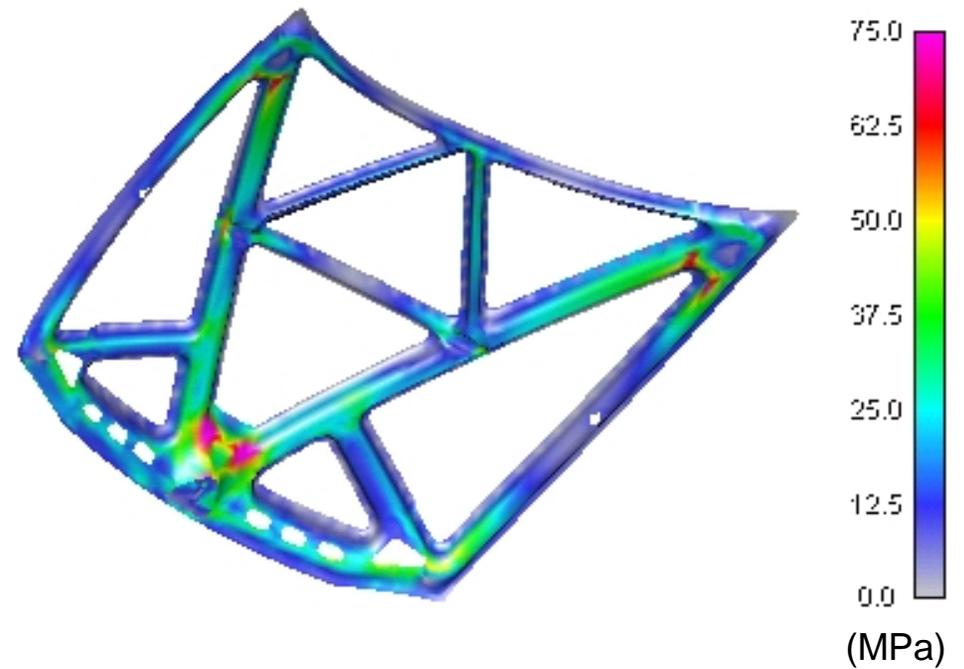
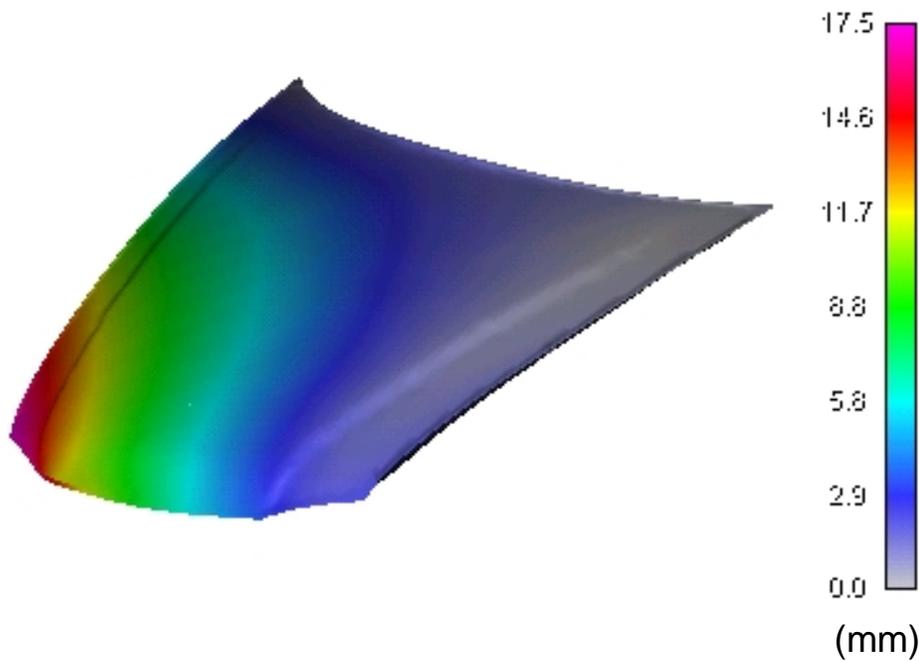
## *Results - Door - Frameless Checkload - Deformation & Stress Plots*





# FEA Calculation

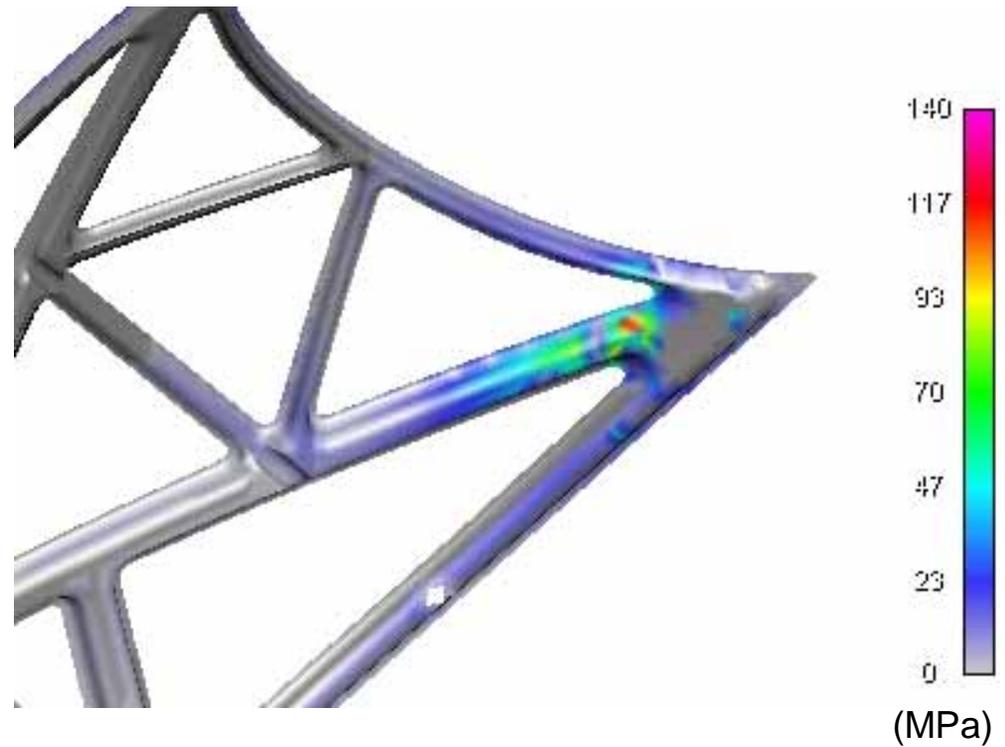
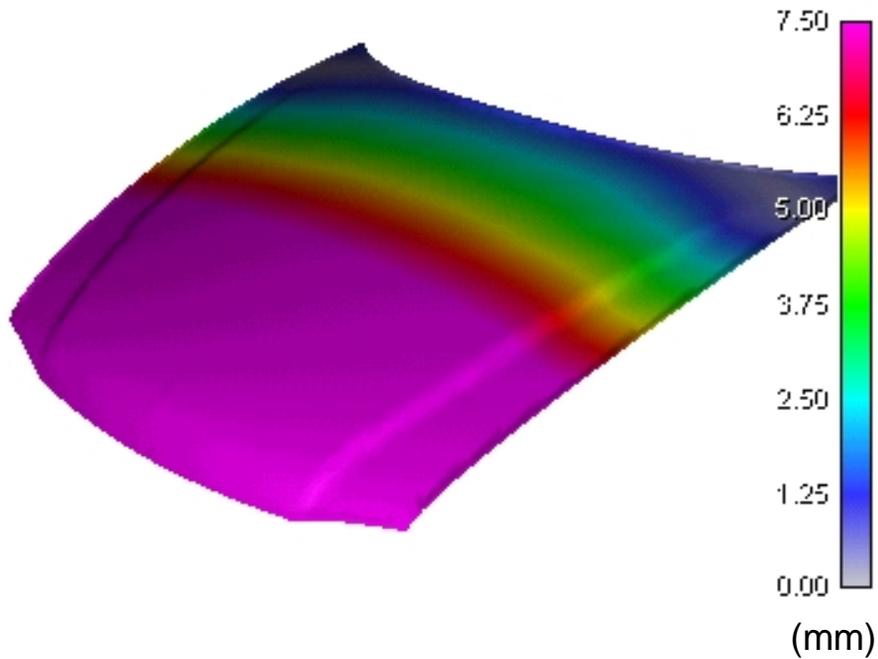
## *Results - Hood - Conventional Torsional Rigidity - Deformation & Stress Plots*





# FEA Calculation

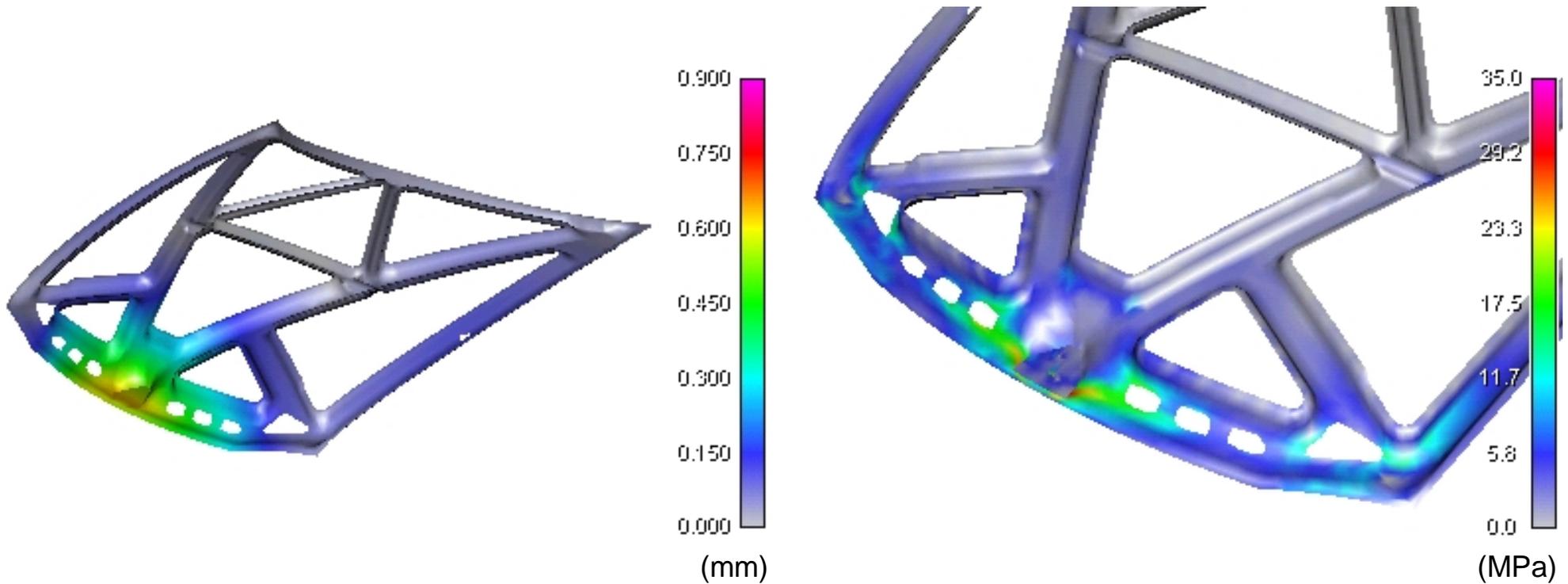
## **Results - Hood - Conventional Bending Stiffness - Deformation & Stress Plots**





## FEA Calculation

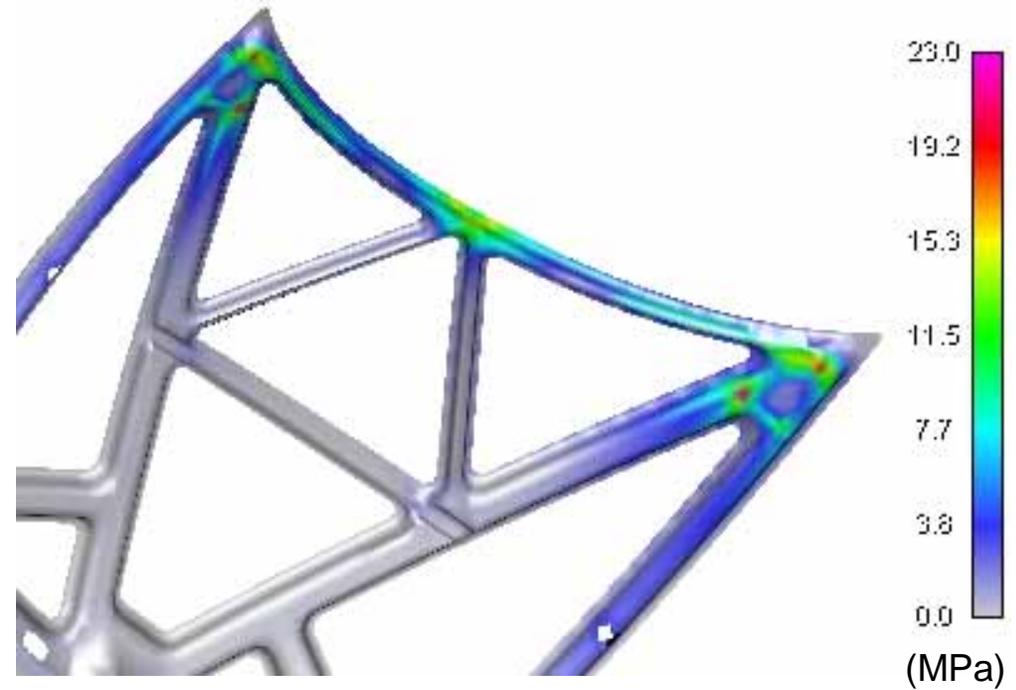
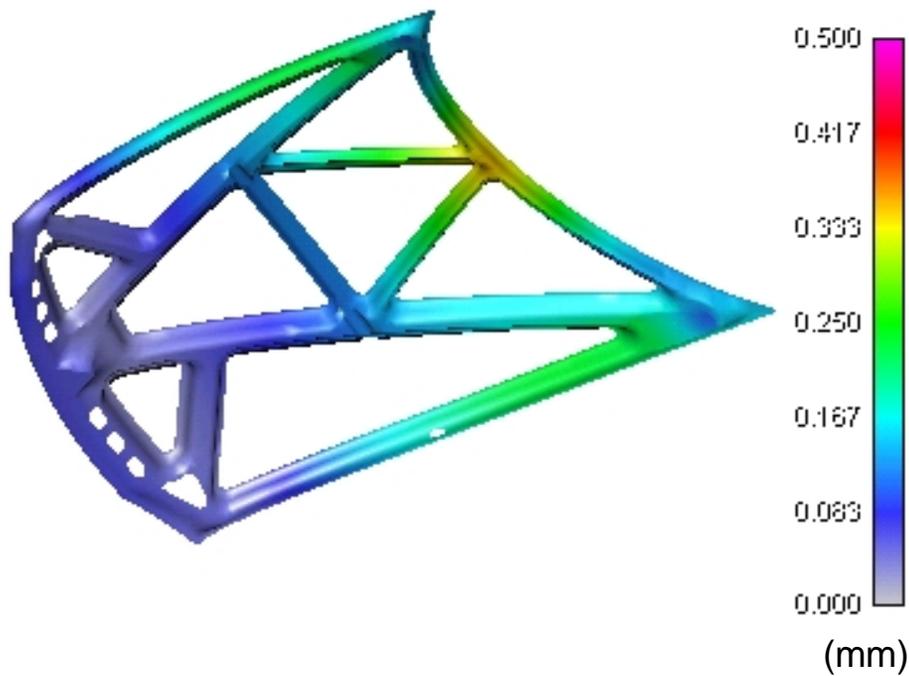
### *Results - Hood - Conventional Front Beam - Deformation & Stress Plots*





# FEA Calculation

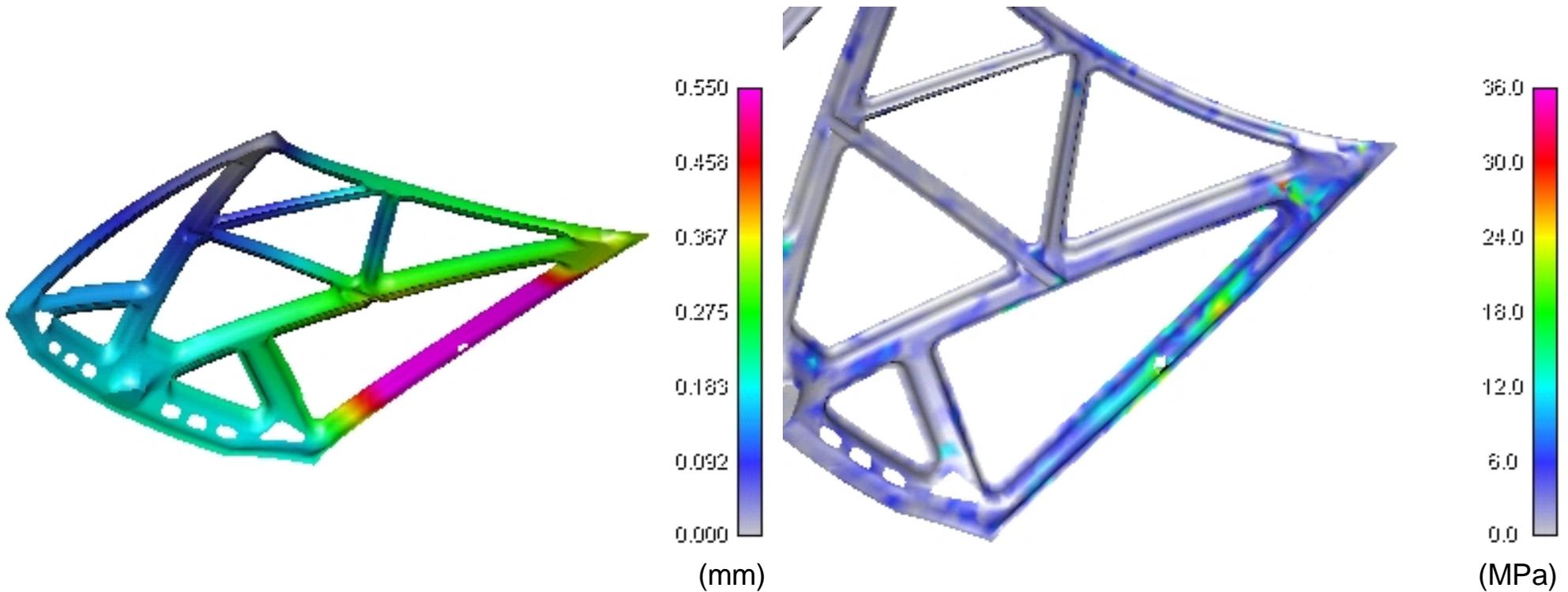
## *Results - Hood - Conventional Rear Beam - Deformation & Stress Plots*





# FEA Calculation

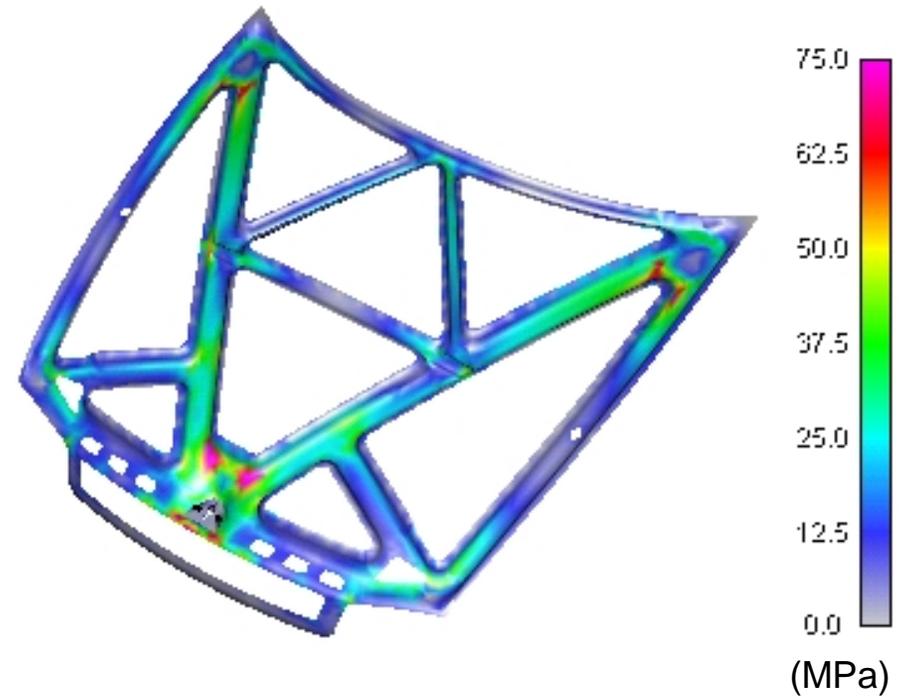
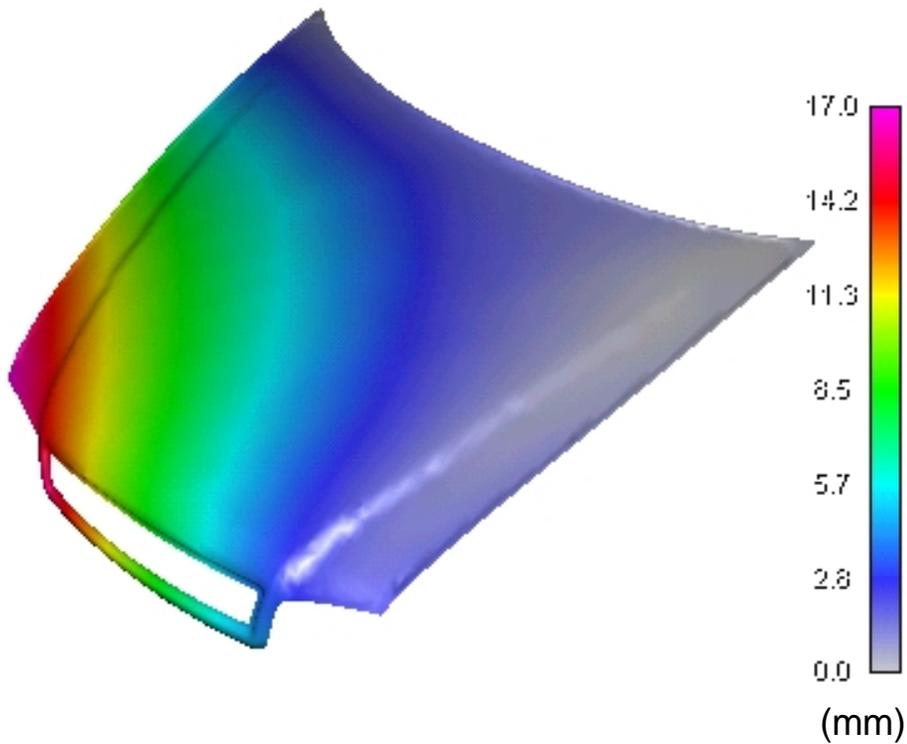
## *Results - Hood - Conventional Side Beam - Deformation & Stress Plots*





# FEA Calculation

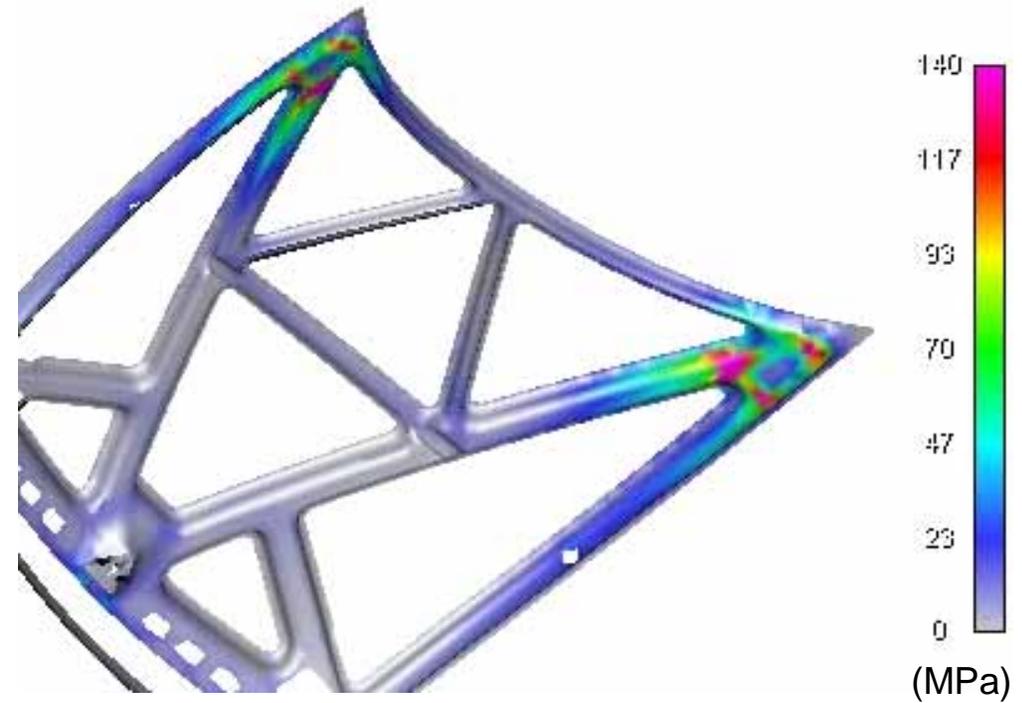
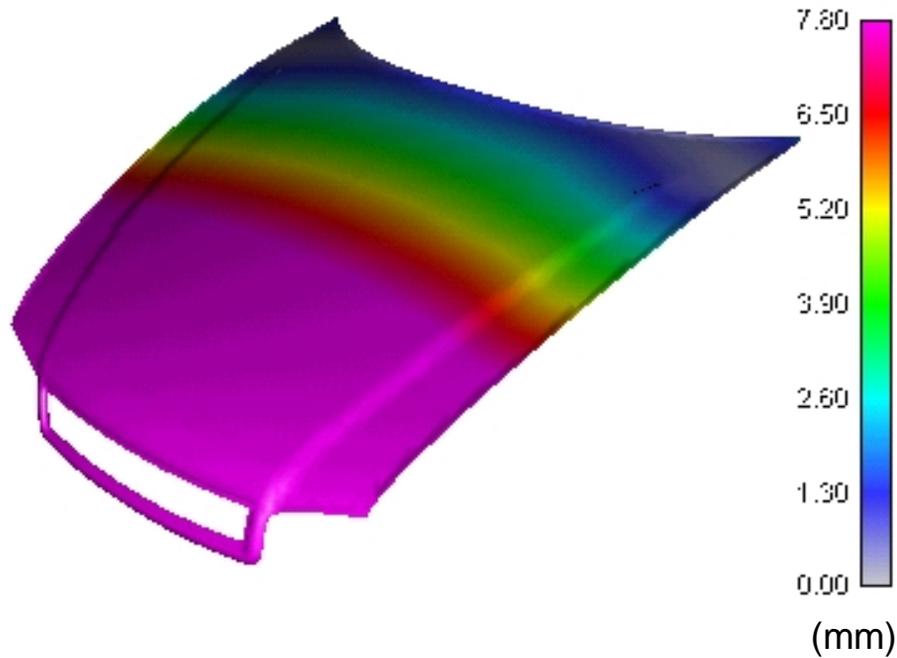
## *Results - Hood - Grille Integrated Torsional Rigidity - Deformation & Stress Plots*





## FEA Calculation

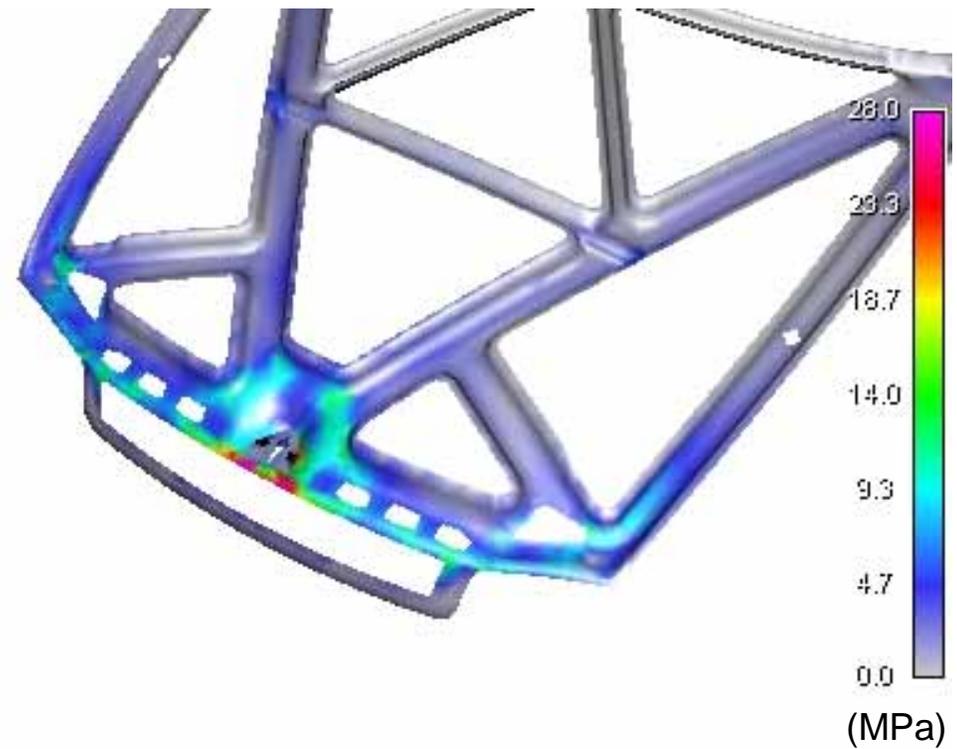
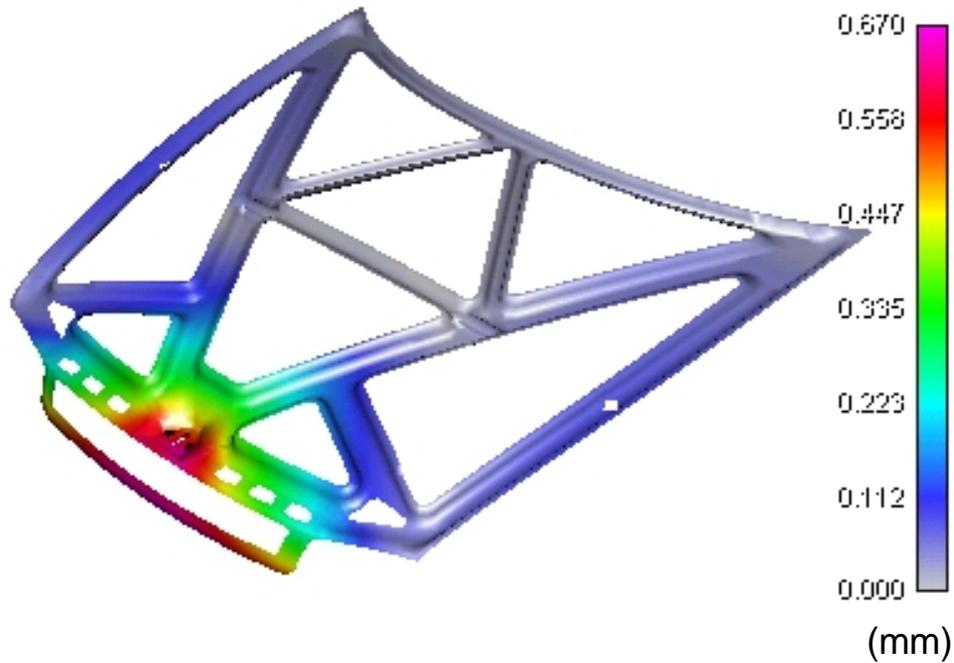
### **Results - Hood - Grille Integrated Bending Stiffness - Deformation & Stress Plots**





# FEA Calculation

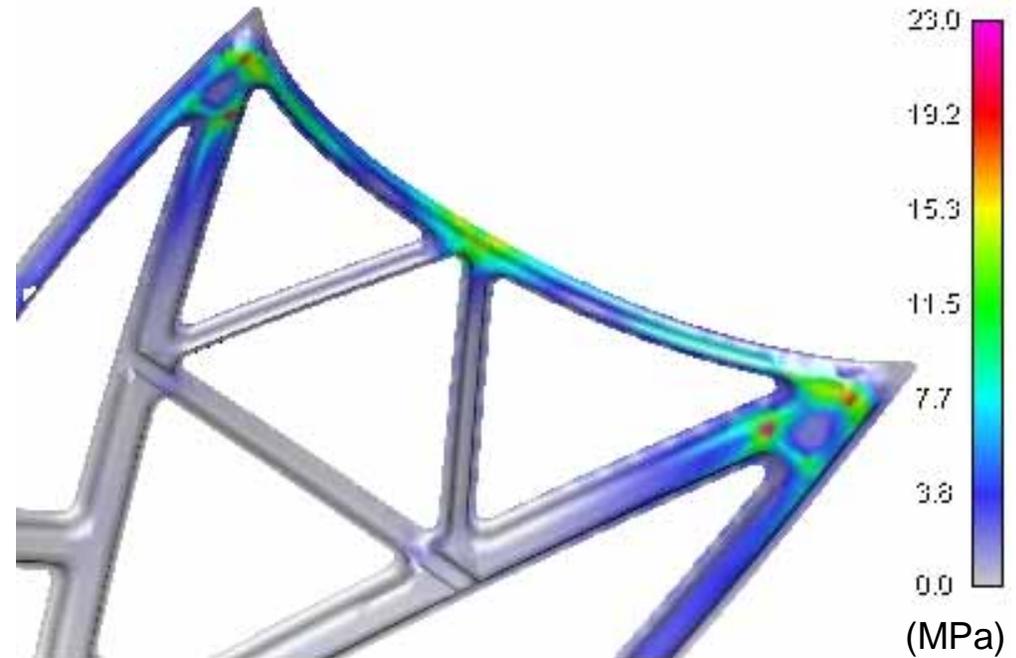
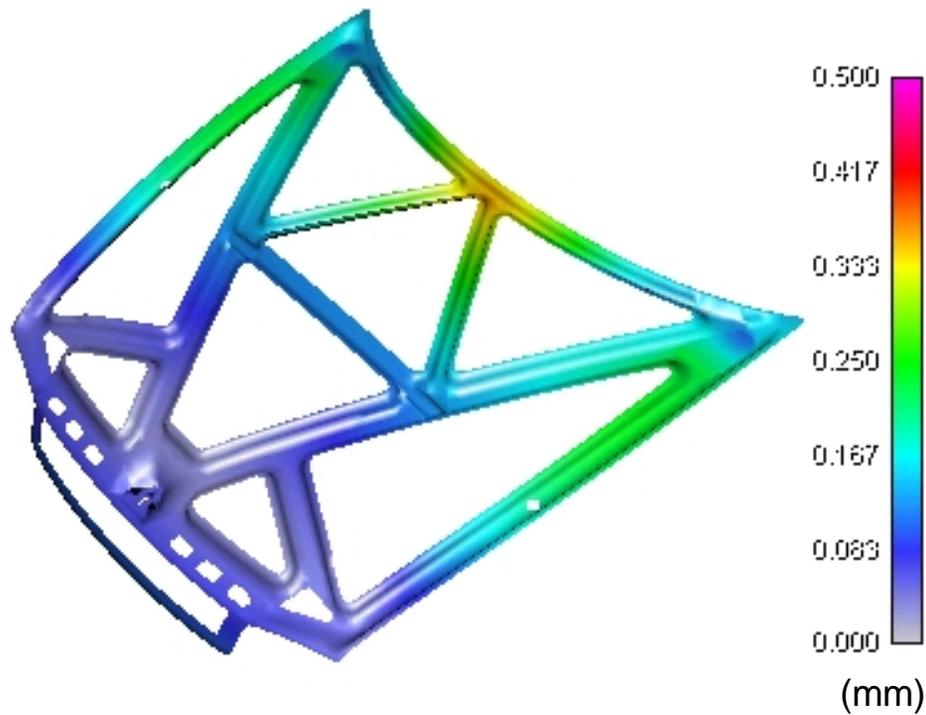
## *Results - Hood - Grille Integrated Front Beam - Deformation & Stress Plots*





# FEA Calculation

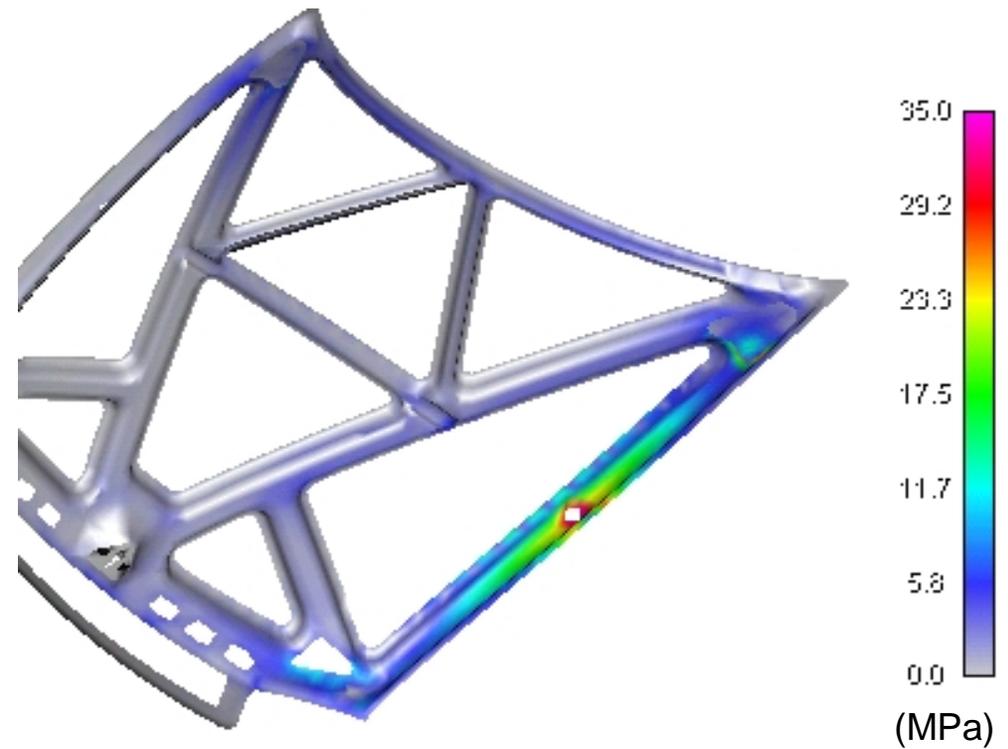
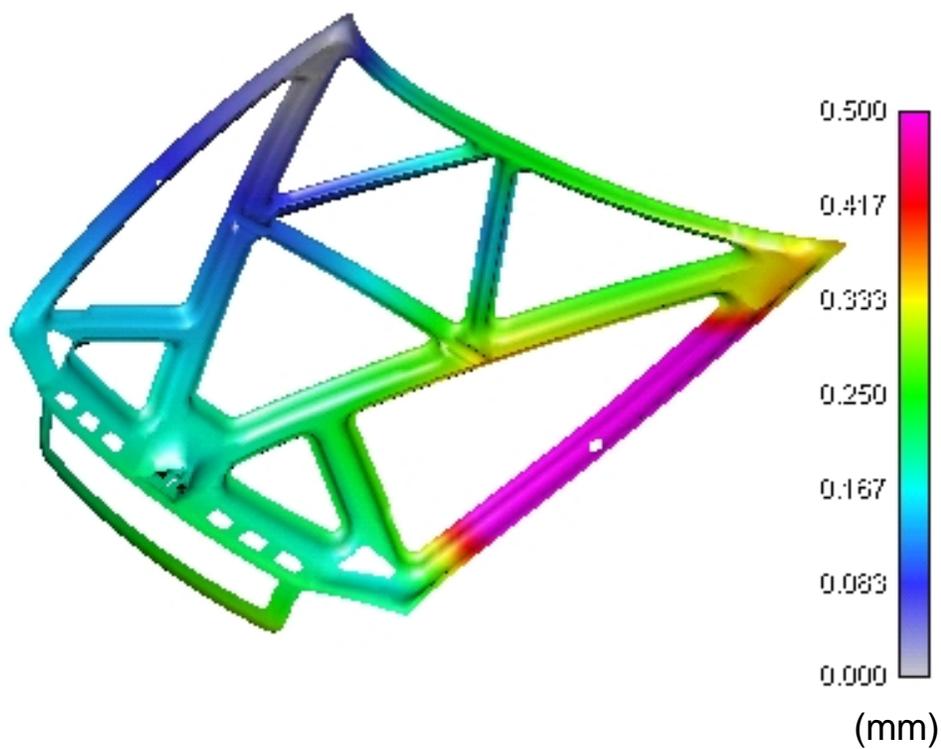
## *Results - Hood - Grille Integrated Rear Beam - Deformation & Stress Plots*





# FEA Calculation

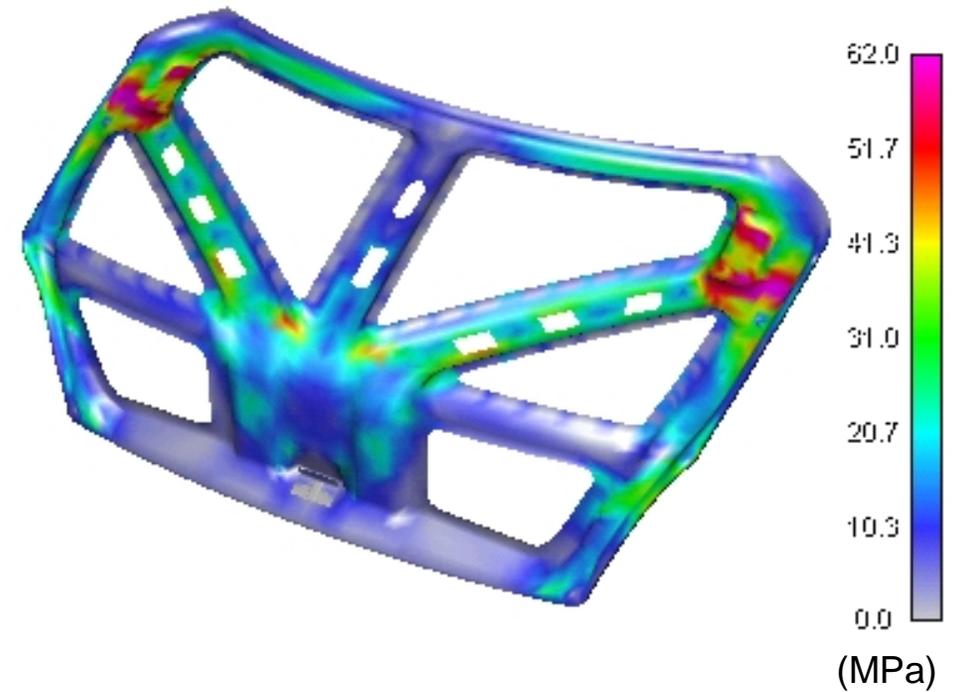
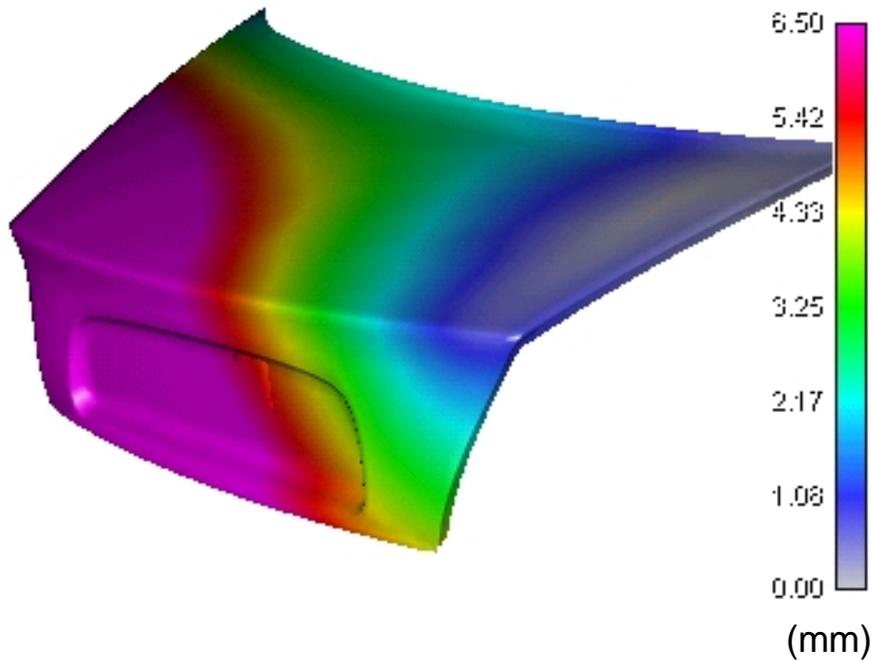
## *Results - Hood - Grille Integrated Side Beam - Deformation & Stress Plots*





# FEA Calculation

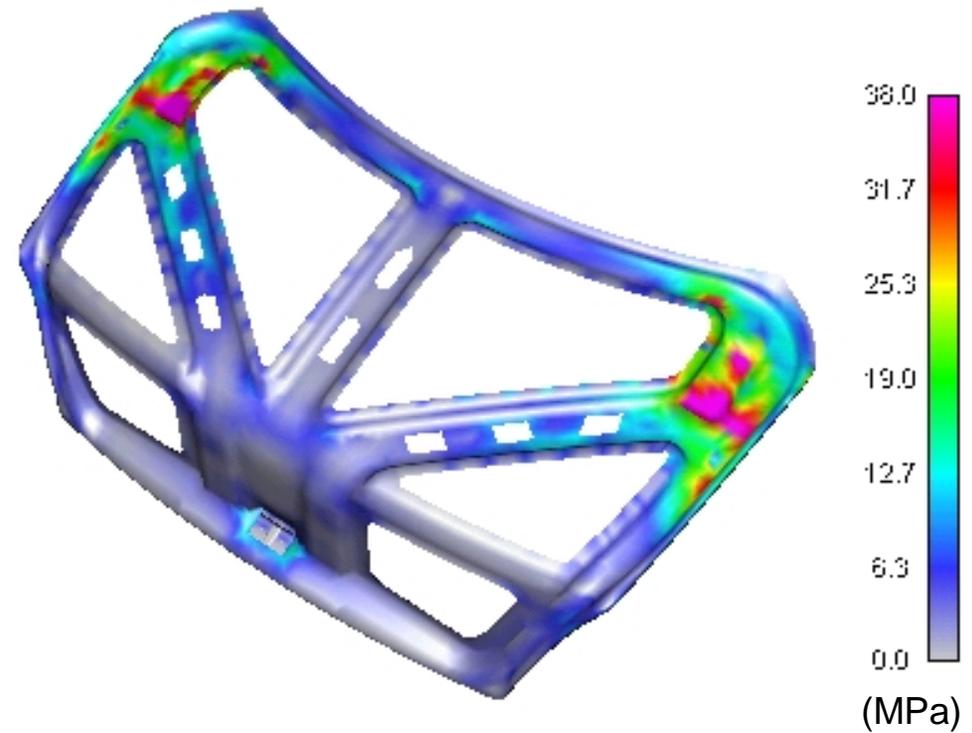
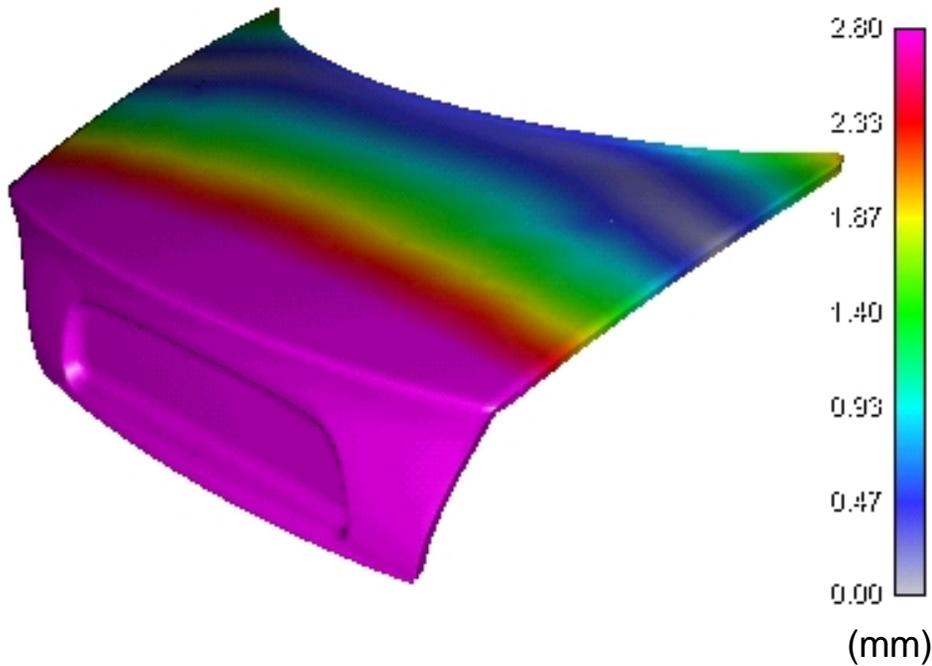
## *Results - Decklid - Conventional Torsional Rigidity - Deformation & Stress Plots*





# FEA Calculation

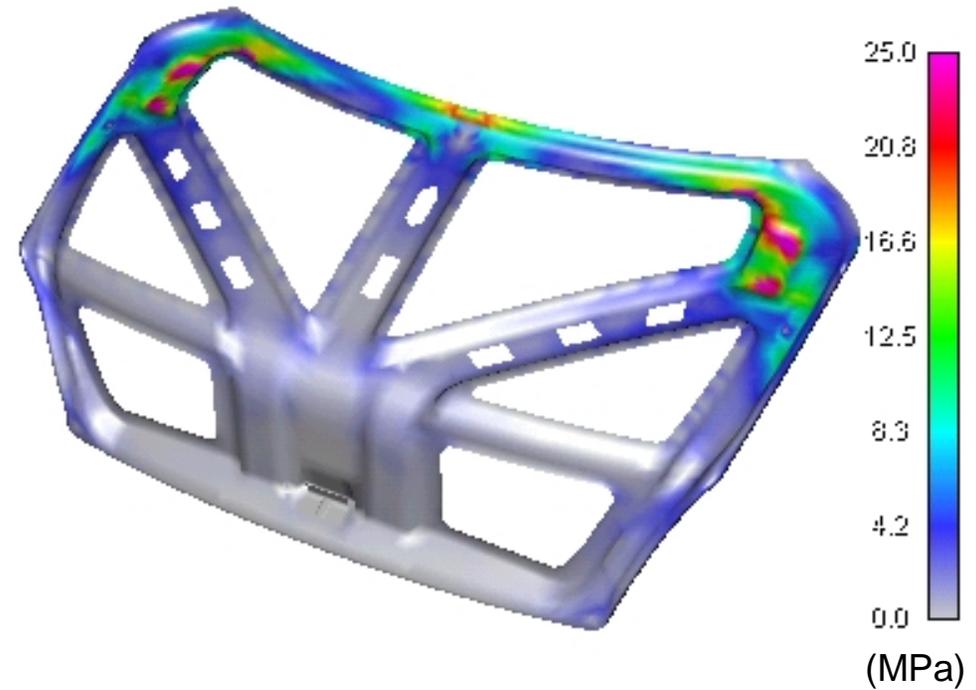
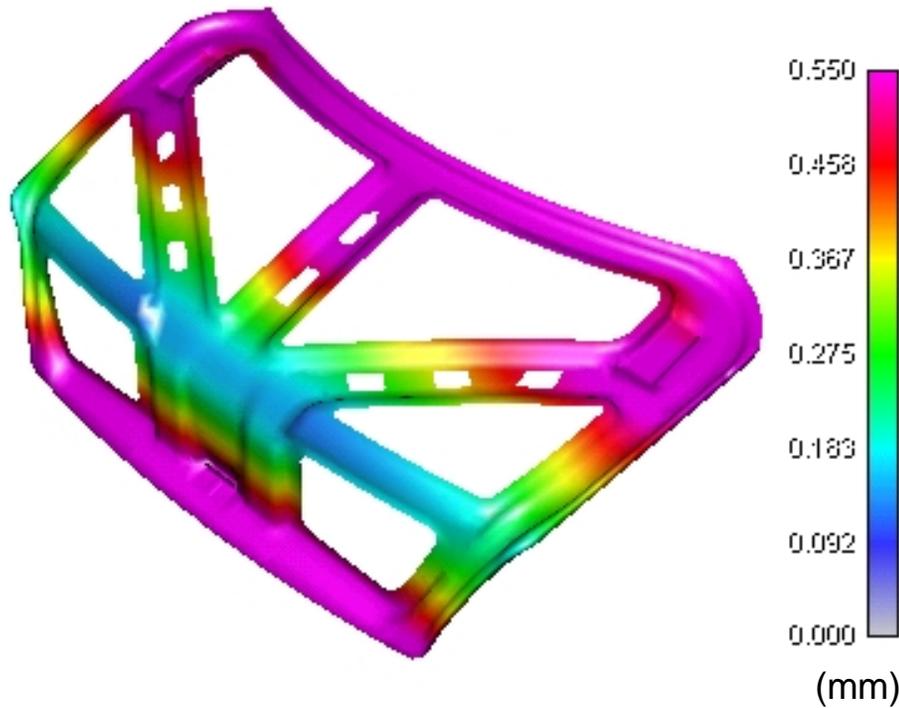
## **Results - Decklid - Conventional Bending Stiffness - Deformation & Stress Plots**





## FEA Calculation

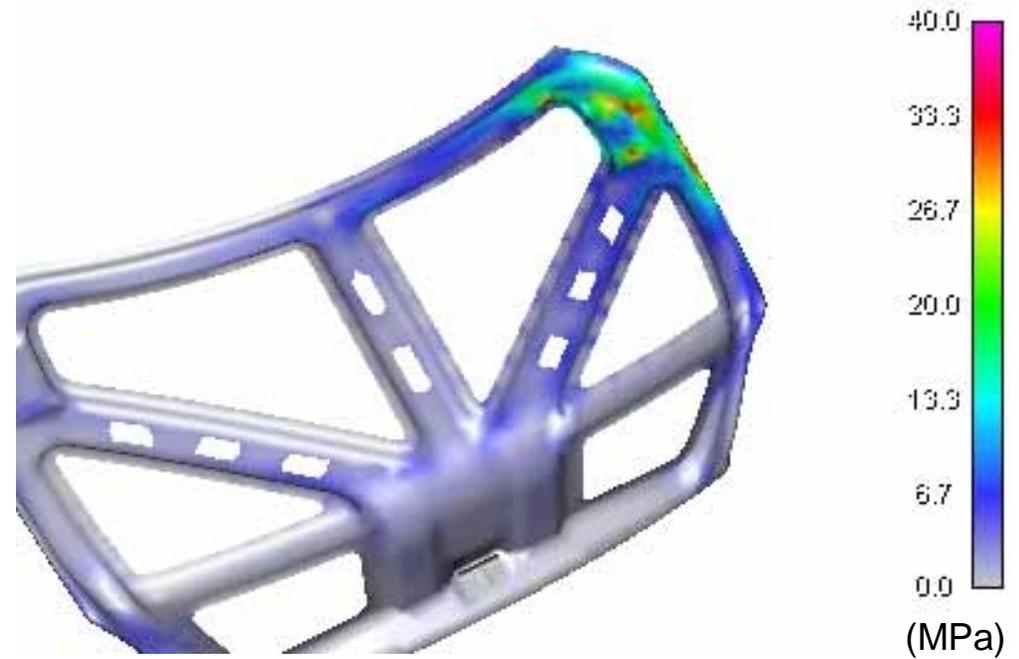
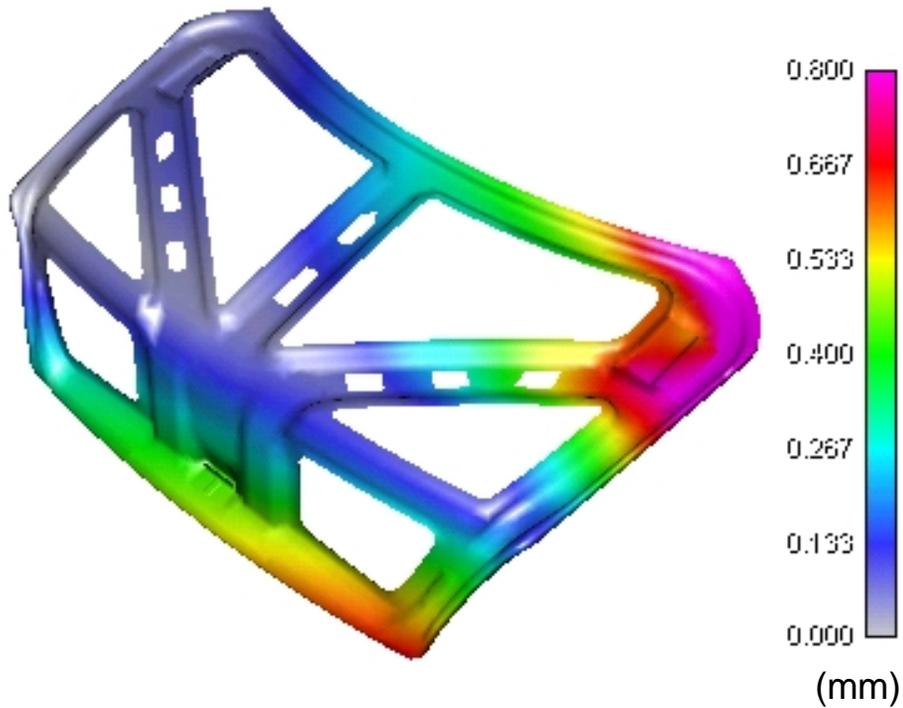
### *Results - Decklid - Conventional Front Beam - Deformation & Stress Plots*





## FEA Calculation

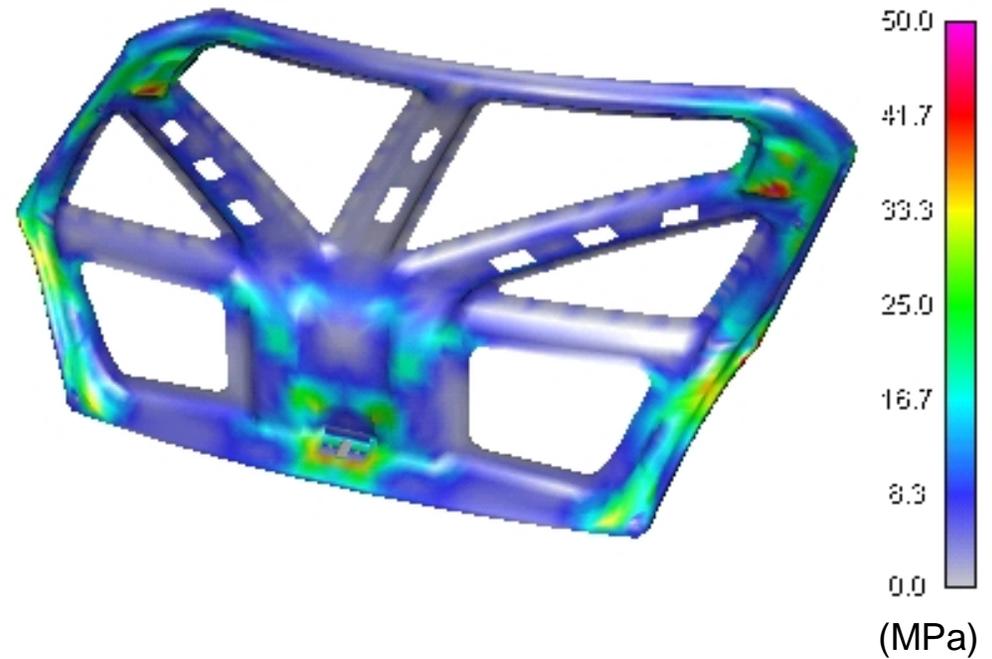
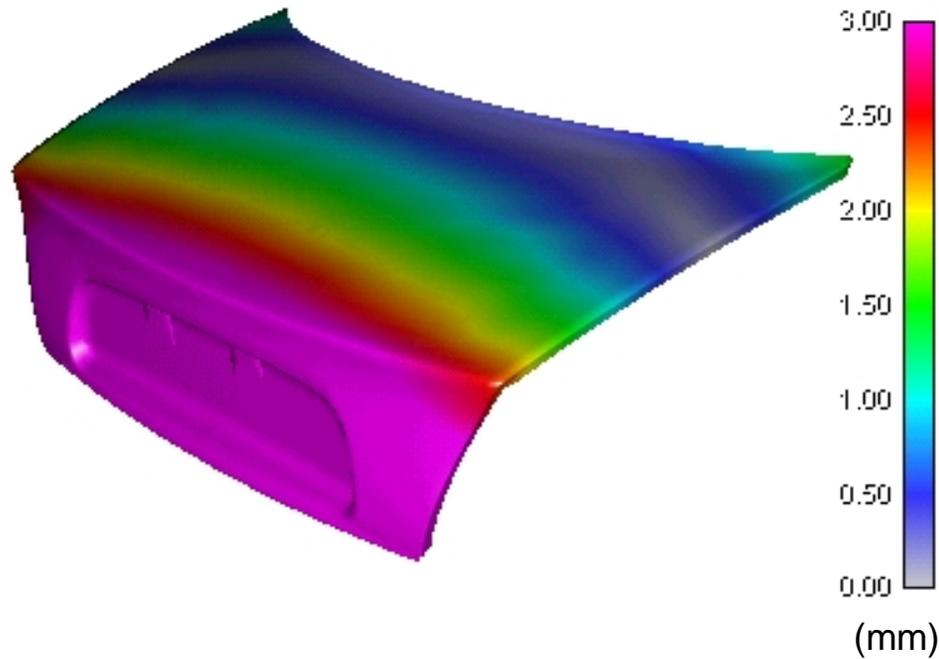
### *Results - Decklid - Conventional Side Beam - Deformation & Stress Plots*





# FEA Calculation

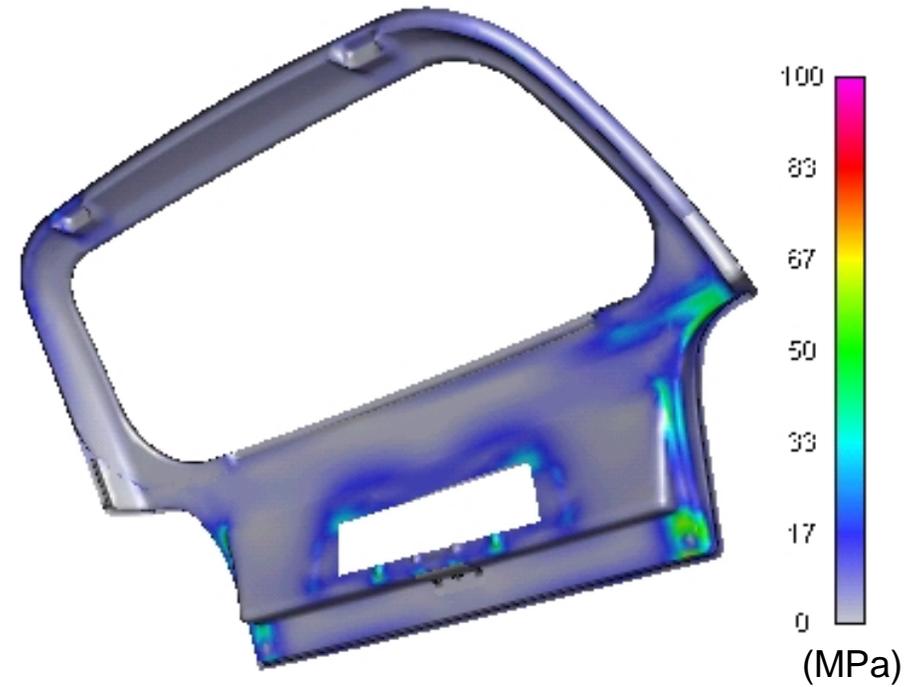
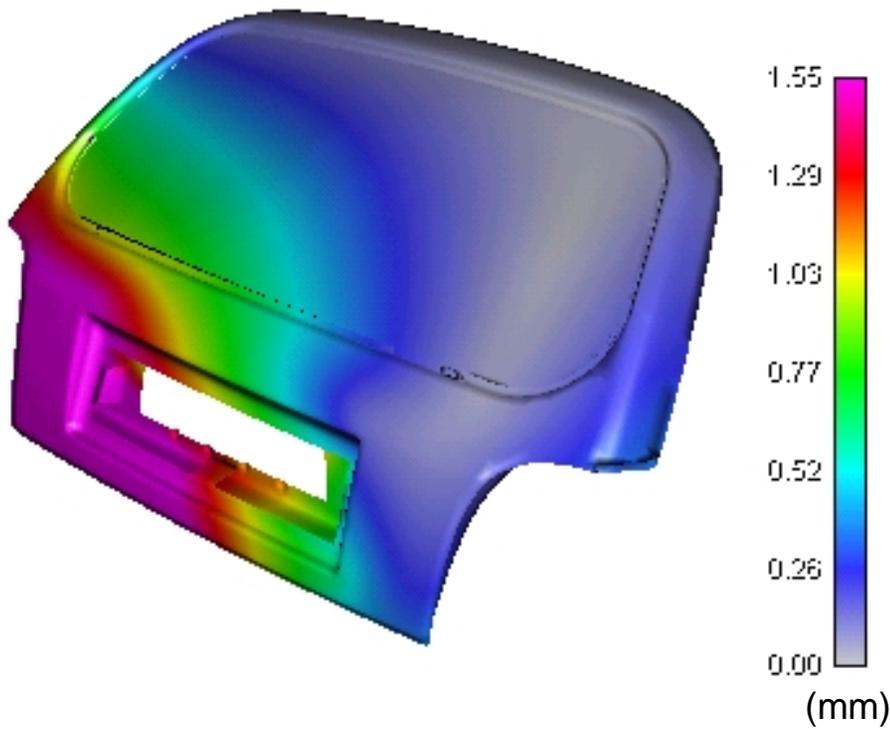
## *Results - Decklid - Conventional Tail Stiffness - Deformation & Stress Plots*





## FEA Calculation

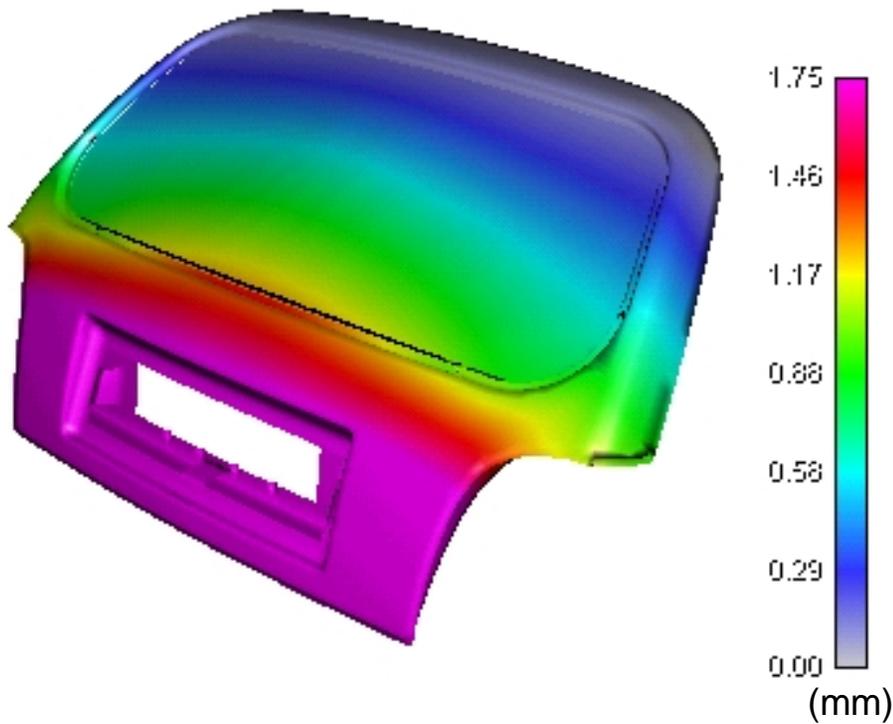
**Results - Hatchback - Tube Hydroformed  
Torsional Rigidity - Deformation & Stress Plots**





## FEA Calculation

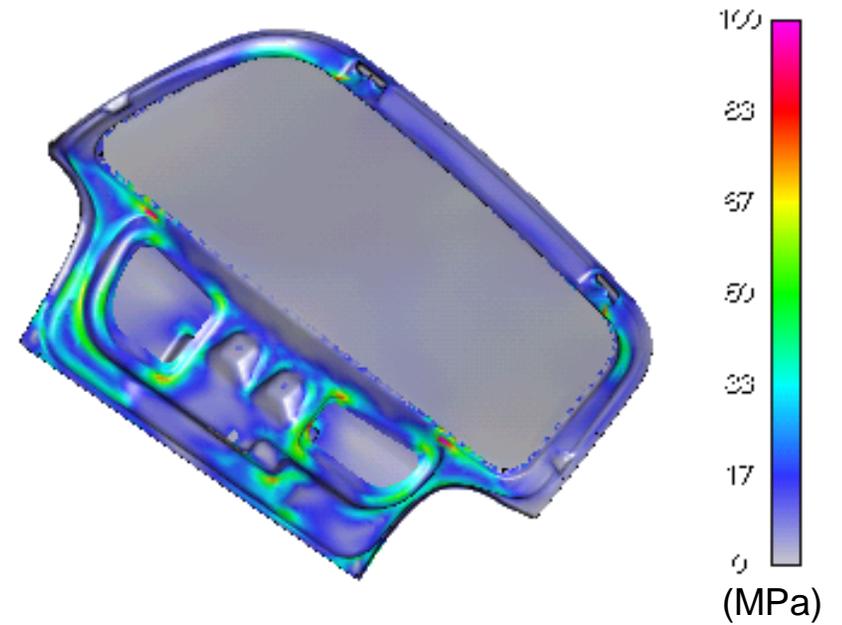
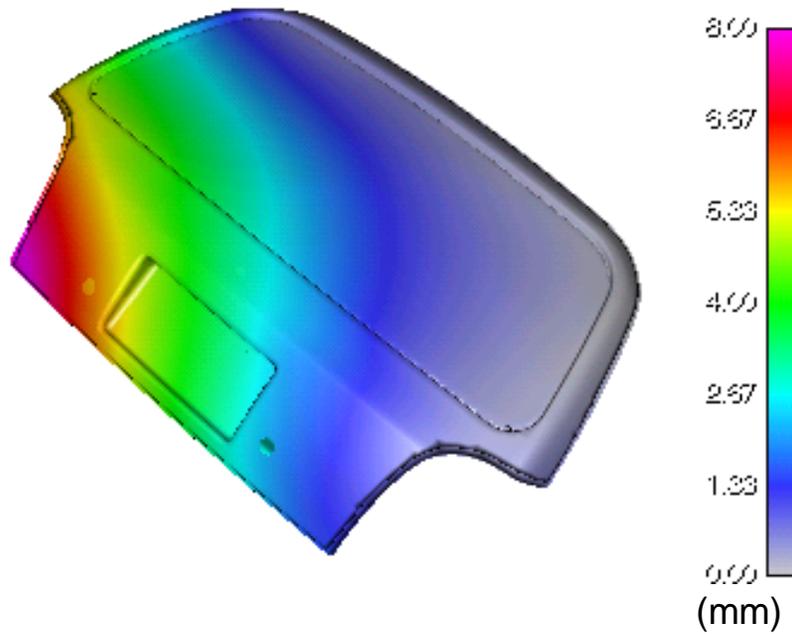
### *Results - Hatchback - Tube Hydroformed Bending Stiffness - Deformation & Stress Plots*





# FEA Calculation

## *Results - Hatchback - Tailored Blank Inner Torsional Rigidity - Deformation & Stress Plots*





# **FEA Calculation**

## ***Results - Hatchback - Tailored Blank Inner***

### ***Bending Stiffness - Deformation & Stress Plots***

